FINAL REPORT

Treatment of N-Nitrosodimethylamine (NDMA) in Groundwater Using a Fluidized Bed Bioreactor

ESTCP Project ER-200829

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14. ABSTRACT
This ESTCP demonstration evaluated the technical effectiveness and cost of a fluidized bed bioreactor (FBR) for treating N-nitrosodimethylamine (NDMA) in groundwater. The demonstration site was the NASA White Sands Test Facility (WSTF) in Las Cruces, NM. The FBR system consisted of a single bioreactor (1 ft diameter x 11.75 ft tall) that operated at flow rates ranging from ~ 1 to 5 gpm, and was fed oxygen, propane, and inorganic nutrients to stimulate propanotrophic bacteria to biodegrade NDMA. The FBR was documented to be an effective means to treat NDMA in groundwater from ~ 1 µg/L to below 4.2 ng/L, the current regulatory discharge limit at WSTF at a 20 minute hydraulic residence time. The FBR also treated N-nitrodimethylamine consistently to < 10 ng/L. The FBR was reliable with greater than 94% up time, and was resilient to upsets including power outages, lack of influent groundwater flow, and absence of propane and nutrients for several days. The cost of a full-scale FBR (125 gpm system)was determined to be significantly less that a comparable ultraviolet system over a 30 year remedial timeframe.

15. SUBJECT TERMS
bioremediation, biodegradation, N-nitrosodimethylamine, NDMA, fluidized bed bioreactor, N-nitrodimethylamine, propane, propanotroph, cometabolic, groundwater

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List of Acronyms and Abbreviations

atm	Atmosphere
BLM	Bureau of Land Management
^{o}C	Degrees Celsius
C	Carbon
CB&I	Chicago Bridge & Iron
CDPH	California Department of Public Health
CFC	Chlorofluorocarbon
cm	Centimeter(s)
CO_2	Carbon dioxide
COC	Chain of Custody
DCM	Dichloromethane (methylene chloride)
DGGE	Denaturing gradient gel electrophoresis
DMN	N-Nitrodimethylamine
DO	Dissolved Oxygen
DoD	Department of Defense
ELAP	Environmental Laboratory Accreditation Program
EPA/USEPA	United States Environmental Protection Agency
ESTCP	Environmental Security Technology Certification Program
ETI	Envirogen Technologies, Inc.
ft	Foot/feet
FBR	Fluidized Bed Reactor
g	Gram(s)
GAC	Granulated Activated Carbon
GC	Gas chromatograph
GC/MS	Gas chromatography/mass spectroscopy
gpm	Gallons per minute
HDPE	High density polyethylene
HMI	Human machine interface
HPLC	High performance liquid chromatography
hr	Hour(s)
HRGC	High resolution gas chromatography
HRMS	High resolution mass spectrometry
HRT	Hydraulic Retention Time
H_2SO_4	Sulfuric acid
IC	Ion chromatography
ID	Inner diameter
in	Inches
kg	Kilograms

kW	Kilowatt(s)
L	Liter(s)
LEL	Lower explosive limit
LHAAP	Longhorn Army Ammunition Plant, Karnack, TX
m^3	Cubic meter(s)
MBR	Membrane Bioreactor
MCL	Maximum Contaminant Level
MDL	Method Detection Limits
min	Minute(s)
mg	Milligrams
mm	Millimeter(s)
µg	Microgram(s)
µM	Micromolar
MPITS	Mid-Plume Interception and Treatment System
N	Nitrogen
N_2	Nitrogen gas
ng	Nanogram(s)
NASA	National Aeronautics and Space Administration
NDMA	N-Nitrosodimethylamine
NEMA	National Electrical Manufacturers Association
NMED	New Mexico Environment Department
NPDES	National Pollutant Discharge Elimination System
O&M	Operation & Maintenance
OD	Optical density
OEHHA	Office of Environmental Health Hazard Assessment
P	Phosphorus
PCE	Tetrachloroethylene
PCR	Polymerase chain reaction
PHG	Public Health Goal
P&ID	Piping and Instrumentation Diagram
PLC	Programmable logic controller
PQL	Practical Quantitation Limit
PVC	Polyvinyl chloride
RPD	Relative Percent Difference
QA	Quality Assurance
QC	Quality Control
QAPP	Quality Assurance Project Plan
rRNA	Ribosomal ribonucleic acid
SCFH	Standard cubic feet per hour
SERDP	Strategic Environmental Research and Development Program

Shaw	Shaw Environmental and Infrastructure
SIM	Selected ion monitoring
SRI	Southwest Research Institute
TCE	Trichloroethylene
TOC	Total Organic Carbon
TSS	Total Suspended Solids
UCMR2	Unregulated Contaminant Monitoring Regulation List 2
UDMH	1,1-Dimethylhydrazine
UV	Ultraviolet
VOC	Volatile Organic Compounds
WSTF	White Sands Test Facility
wt	weight

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Acknowledgements

This Environmental Security Technology Certification Program (ESTCP) project was a collaborative effort among scientists and engineers at Shaw Environmental, Inc. (Shaw; A wholly-owned subsidiary of CB&I, Lawrenceville, NJ), Envirogen Technologies, Inc. (ETI; Rancho Cucamonga, CA), and the White Sands Test Facility (WSTF, Las Cruces, NM). We wish to thank the WSTF facility staff and subcontractors supporting the project demonstration. In particular, special thanks to Mr. Michael Zigmond and Mr. Ray Baker of WSTF for their consistent dedication to the project study and its success. We also with to thank ESTCP for their financial support, and Dr. Andrea Leeson, the Environmental Restoration Program Manager at ESTCP for her guidance. Finally, in large degree, the overall success of the project is a direct function of the personnel that operated the system and conducted the experiments on a daily basis. Ms. Celeste Lewis and Mr. Sam Wong of ETI and Ms. Sheryl Streger of Shaw demonstrated persistent dedication during the field piloting phase of the study that lead to the project success. Their daily efforts ultimately lead to the quality experimental results and findings demonstrated during this project.

Executive Summary

N-Nitrosodimethylamine (NDMA) is present in groundwater and drinking water from industrial, agricultural, water treatment, and military/aerospace sources. NDMA is a suspected human carcinogen and an emerging groundwater contaminant that has been detected at a number of Department of Defense (DoD) and National Aeronautics and Space Administration (NASA) sites involved in the production, testing, and/or disposal of liquid propellants containing unsymmetrical dimethylhydrazine (UDMH). NDMA was a common contaminant in UDMH-containing fuels (e.g., Aerozine-50) and is also produced when these fuels enter the environment through natural oxidation processes. Currently, the most effective treatment technology for NDMA in groundwater is pump-and-treat with ultraviolet irradiation (UV). However, this approach is expensive because it requires high energy input to effectively reduce the levels of NDMA to meet regulatory requirements. The objective of this ESTCP project was to demonstrate and validate the use of an advanced bioreactor design, a fluidized bed bioreactor (FBR), in the field for the *ex situ* treatment of NDMA from part-per-billion (µg/L) influent concentrations to low part-per trillion (ng/L) effluent concentrations.

This ESTCP project builds upon the successful results from SERDP Project ER-1456, the objective of which was to examine the potential for *in situ* and *ex situ* biodegradation of NDMA under aerobic conditions using cometabolic approaches. The key findings of that project were as follows: (1) the propanotroph *Rhodococcus ruber* EN425 cannot grow on NDMA, but is capable of degrading NDMA to innocuous products, including formate, nitrate, nitrite, methylamine, and carbon dioxide, during growth on propane; (2) biodegradation of NDMA from typical groundwater concentrations (e.g., 1-100 µg/L) to low ng/L concentrations by *R. ruber* ENV425 is achievable; (3) similar propanotrophs capable of degrading NDMA are indigenous to other groundwater environments, and these organisms can be stimulated to degrade NDMA through the addition of propane and oxygen; and (4) propane does not appear to be a significant inhibitor of NDMA biodegradation by many propanotrophs even though the reaction is cometabolic. A laboratory-scale propane fed FBR was operated for eight months and observed to be capable of degrading NDMA from 10-20 µg/L to < 100 ng/L, and further to < 10 ng/L when optimized. Based on the fundamental studies with propanotrophs, and the successful laboratory FBR study, the current project examined the effectiveness of a propane-fed FBR at the field scale for NDMA treatment.

The field-scale FBR was operated at the NASA White Sands Test Facility (WSTF) in Las Cruces, NM. The facility encompasses approximately 28 square miles, and is situated on the U.S. Army's White Sands Missile Range. Historically, this facility evaluated rocket engines, space flight components, and rocket propulsions systems. More recently, it continues to test such systems, but also serves other testing functions for NASA including materials assessment, hazard assessments, space flight system testing, and launch and landing system testing. The pilot-scale FBR was located at the newly constructed full-scale treatment facility (Mid-Plume Interception and Treatment System; MPITS) at WSTF. The MPITS is designed to treat 125 gpm of groundwater flow from various extraction wells located within a plume of NDMA at the site.

Treatment of the water involves the use of an air stripper for volatile organic contaminants (VOCs; primarily Freon-113, CFC-11 and TCE) followed by a low pressure lamp UV photolysis system for NDMA treatment. A secondary contaminant from rocket fuel, N-nitrodimethylamine (DMN) is also present in the groundwater, and its treatment within the FBR was also examined.

The FBR is an efficient fixed-film bioreactor. It consists of a reactor vessel containing media with a high surface area (usually sand or GAC) to foster the growth of microbial biomass. The high biomass achievable within the FBR bed makes it appreciably more efficient for water treatment than many other types of biological reactor systems. This reduces the reactor size and, subsequently, the cost of treatment. The pilot-scale FBR (1-5 gpm influent flow) was operated for ~ 1 year on the actual site water using coconut shell based granular activated carbon (GAC) media under various operating conditions. Propane, oxygen, and inorganic nutrients were fed to the system to support microbial growth and NDMA biodegradation. The pilot FBR treated water that had passed through the air stripper to remove VOCs for a majority of the study, allowing direct cost and performance comparison with the existing UV system.

The system was operated in seven different phases (Phase I to Phase VII), including an initial 83 days of abiotic loading (Phase I) until influent and effluent NDMA (and DMN) concentrations were equivalent. This phase was conducted to ensure that subsequent NDMA removal was through biological degradation rather than adsorption to the GAC media. Phase II consisted of a seven day period in which strain ENV425 was inoculated and the FBR was placed in recycle to allow attachment of the organisms to the FBR media. Phase III was conducted for a 90-day period. Biomass growth was promoted, the hydraulic residence time (HRT) in the FBR was decreased from 60 minutes to 30 minutes, and gas and nutrient additions were adjusted to provide adequate quantities for microbial growth but limiting excess. Phase IV entailed steady-state operation with consistent gas flow, and evaluation of FBR performance at residence times ranging from 30 minutes to 10 minutes. After the steady-state phase, a series of feed and electrical shutdown studies were conducted to assess how the FBR responded to typical system upsets (Phase V; 90 days), and then the air-stripper was bypassed to evaluate the impact of VOCs on the treatment of NDMA in the FBR (Phase VI; 27 days). In Phase VII, the unit was decommissioned and shipped off-site after approximately 1 year of operation.

Complete breakthrough of NDMA and DMN were observed during Phase I prior to culture inoculation indicating that the adsorptive capacity of the GAC media was saturated. During Phase II microbial inoculation, the system was set into complete recycle for several days to allow attachment of ENV425 to the GAC media, and then influent flow was initiated to provide a 60 minute HRT in the FBR. During Phase III (Day 90-180), the HRT was gradually decreased from 60 minutes to 30 minutes. NDMA degradation was apparent shortly after inoculation, with effluent concentrations declining from ~1 µg/L (equal to the influent) to < 10 ng/L within 25 days after ENV425 was introduced. When the HRT was decreased from 60 minutes to 40 minutes, the effluent NDMA concentrations increased to above 20 ng/L, but then declined again to < 10 ng/L by Day 165, when the HRT was reduced further to 30 minutes. NDMA in the effluent remained < 10 ng/L for the duration of Phase III. Much like NDMA, DMN concentrations declined to < 10 ng/L during the first 25 days after inoculation with ENV425, and

then they increased marginally when the HRT was reduced from 60 minutes to 40 minutes. By the end of Phase III, DMN was consistently < 10 ng/L.

During Phase IV steady-state operation at an HRT of 30 minutes, the average influent NDMA concentration was 1.13 ± 0.003 μg/L and the average effluent concentration was 3.3 ± 0.6 ng/L. DMN averaged 0.58 ± 0.09 μg/L in the influent, and the effluent was consistently < 10 ng/L (MDL). The feed flow was increased such that a 20 minute HRT in the FBR was achieved. NDMA concentrations in the influent and effluent averaged 0.72 ± 0.39 μg/L and 2.3 ± 0.8 ng/L, respectively, at the 20 minute HRT. DMN averaged 0.38 ± 0.21 μg/L in the influent, and the effluent was consistently < 10 ng/L (MDL). On Day 239 through Day 270, the system HRT was reduced further to 10 minutes. At this HRT, NDMA effluent values began to increase somewhat. NDMA concentrations in the influent and effluent averaged 0.85 ± 0.19 μg/L and 4.6 ± 1.8 ng/L, respectively. DMN averaged 0.47 ± 0.10 μg/L in the influent, and the effluent remained < 10 ng/L (MDL). The data during Phase IV clearly showed that the FBR was capable of reducing NDMA to below the WSTF regulatory limit of 4.2 ng/L at a 20 minute HRT. An effluent concentration < 10 ng/L was consistently met at the 10 minute HRT, but effluent concentrations exceeded the revised WSTF discharge limit of 4.2 ng/L after a few weeks of operation. The study also showed that concurrent NDMA and DMN removal is possible within the same FBR system.

The feeds of propane and inorganic nutrients were shut off from Days 270-279 (10 minute HRT) to simulate the effects of a failure in these systems. NDMA concentrations in the effluent slightly exceeded 10 ng/L on Day 272, but values did not increase further toward the 1 μg/L influent value. The data suggest that the FBR is resilient to a shutdown of propane and/or nutrients over the short term. After the propane and nutrient feeds were reestablished, NDMA effluent concentrations below 10 ng/L were observed within eight hours. After seven days, the effluent NDMA concentrations were below 4.2 ng/L. The concentration of DMN increased to > 45 ng/L during the 9 day period when the propane and nutrient feeds were off and remained in this vicinity through Day 287, when the system shutdown experiment was conducted. After a scheduled feed shutdown experiment on Days 287-315, NDMA in the effluent was < 10 ng/L (influent concentration 1.46 μg/L) at the first collection point after restarting groundwater flow, with subsequent NDMA samples over the next 25 days declining to below 4.2 ng/L at a 10 minute HRT. DMN was < 10 ng/L upon restart of the system. Results from the nutrient and feed shutdown experiments generally indicated that the FBR could recover to treatment levels below 10 ng/L within hours to a few days after restart.

On Days 350-377 (Phase VI), a limited study was conducted in which the air stripper was bypassed and water contaminated with TCE and Freon 11 in addition to NDMA was allowed to enter the FBR. A low concentration of 1,2-dichlorobenzene was also present in the water. Treatment of NDMA to less than 100 ng/L in the presence of site co-contaminants was the objective. During the testing at an HRT of 10 minutes, influent Freon 11, TCE, and 1,2-dichlorobenzene concentrations averaged 28 ± 3, 16 ± 1, and 16 ± 1 μg/L, respectively. Effluent Freon 11 averaged 18 ± 2 μg/L, effluent TCE averaged 0.7 ± 0.2 μg/L, and effluent 1,2-

dichlorobenzene averaged 0.7 ± 0.2 μg/L during the testing. The observed declines in TCE and 1,2-dichlorobenzene may have been due to adsorption or biodegradation, or a combination of these processes. For Freon 11, adsorption is the most likely loss mechanism, as ENV425 was observed to not biodegrade this compound in batch studies. The NDMA in the effluent increased slightly from 4 ng/L to 14 ng/L after the water with VOCs passed through the FBR. DMN remained < 5 ng/L during and after the addition of the VOCs. By Day 363, effluent NDMA concentrations were < 8 ng/L, declining to < 6 ng/L by Day 375. The data suggest that short-term contact with low concentrations of TCE and Freon 11 had no significant impact on NDMA treatment.

A cost comparison between the FBR and a comparable UV system operating at 125 gpm and 1 μg/L NDMA was conducted based on the data from the pilot-scale FBR and from the full-scale UV system at WSTF. Life-cycle costs for the UV and FBR systems were based on the capital equipment costs, the engineering and installation costs, and the overall operating costs of chemicals, electricity, and parts replacement. Although several assumptions must be made to compare the systems, a general cost analysis provides the following information:

- Capital costs for UV are lower compared to the FBR treatment system at the NDMA concentration treated.
- Installation/engineering costs for both technologies used scaling factors that were a direct function of the capital cost. Hence, the UV installation/engineering cost by definition was less expensive than the FBR.
- Operating costs for chemicals favored the UV system, but the difference over 30 years was not considered significant (less than $15,000)
- Operating costs for the electricity and the parts replacement significantly favor the FBR significantly over the UV system. The UV electrical demand is 3X higher than the FBR, while the need for UV lamp replacement every 1.4 years makes up over half the 30-year remediation cost for UV parts. If the replacement frequency of the lamps increases over time, the overall costs will increase.
- Overall costs over the 30-year remediation project favor the FBR over the UV system by approximately $900,000, or roughly 35% with the primary savings being related to lower electrical and maintenance costs.

In summary, a propane-fed FBR was observed over more than one year of field operation to be an effective means to treat NDMA in groundwater to below 4.2 ng/L, the current regulatory discharge requirements at the WSTF site where the demonstration was conducted. The FBR also treated DMN consistently to < 10 ng/L. The system was reliable, required ≤ 10 hours per week of operator attention, and was resilient to upsets including power outages, lack of influent groundwater flow, and absence of propane and nutrients for several days. In addition, Overall costs over the 30-year remediation project favor the FBR over the UV system by approximately $900,000, or roughly 35% less than the total 30-year cost of a UV system (2.53M) at a 125 gpm flow rate. Significantly lower energy costs make the FBR a more sustainable technology than UV for future applications.

1.0 Introduction

The origin of N-Nitrosodimethylamine (NDMA) in groundwater and drinking water includes industrial, agricultural, water treatment, and military/aerospace sources. NDMA is a suspected human carcinogen and an emerging groundwater contaminant that has been detected at a number of Department of Defense (DoD) and National Aeronautics and Space Administration (NASA) sites involved in the production, testing, and/or disposal of liquid propellants containing unsymmetrical dimethylhydrazine (UDMH). NDMA is a known impurity in UDMH-based fuels (such as Aerozine-50) and it can be formed through oxidation of UDMH in the environment or after exposure to hydrogen peroxide (Fleming et al., 1996; Mitch et al., 2003; Lunn and Sansone, 1994). DoD and NASA Sites with NDMA in groundwater include former Air Force Plant PJKS (CO); the White Sands Test Facility (NM); the Rocky Mountain Arsenal (CO); Jet Propulsion Labs (CA) and Edwards Air Force Base (CA). NDMA plumes have also been detected at aerospace contractor sites, such as Aerojet in CA (Girard, 2000). Both Los Angeles and Orange Counties in California have reported NDMA in groundwater supply wells (CDPH, 2013).

Currently, the most effective treatment technology for NDMA in groundwater is pump-and-treat with ultraviolet irradiation (UV). However, this approach is expensive because it requires high energy input to effectively reduce the levels of NDMA. The objective of this ESTCP project was to demonstrate and validate the use of an advanced bioreactor design, a fluidized bed bioreactor (FBR), in the field for the treatment of NDMA to required regulatory levels. This ESTCP project was a collaborative effort among scientists and engineers at Shaw Environmental, Inc (Shaw: a subsidiary of CB&I, Lawrenceville, NJ), Envirogen Technologies, Inc. (Rancho Cucamonga, CA), and the White Sands Test Facility (WSTF, Las Cruces, NM).

1.1 Background

The effective treatment of NDMA in groundwater requires that the concentrations of the compound be reduced from a few to several hundred μg/L to low ng/L concentrations. To date, no pure bacterial cultures have been isolated that can utilize NDMA as a sole source of carbon and energy. Moreover, in many instances, bacteria have been observed to have a lower threshold concentration for an organic substrate below which degradation ceases (Alexander, 1994). One theory for this threshold phenomenon is that, as the concentration of a substrate decreases during degradation, a point is reached in which the energy required to maintain a bacterial cell is no longer met by the quantity of substrate available (Schmidt et al., 1985). At this point cells die and degradation ceases leaving residual substrate (i.e., organic contaminant). Lower threshold values vary appreciably by compound and cell type; concentrations ranging from approximately 0.0015 to 100 μg/L have been reported (Alexander, 1994). The absence of cultures that can use NDMA for growth and the aforementioned threshold phenomenon are both important considerations when evaluating bioremediation strategies for NDMA. These observations make it unlikely that a bacterial strain will be able to grow on a few μg/L of NDMA and reduce its concentration to ng/L levels. However, the degradation of NDMA by a co-metabolic process in which the bacterium actually grows on a secondary substrate (such as propane, toluene, butane, etc.)

and degrades NDMA fortuitously, may allow threshold limitations to be overcome, and low concentrations to be achieved.

This ESTCP project builds upon the successful results from SERDP Project ER-1456, the objective of which was to examine the potential for *in situ* and *ex situ* biodegradation of NDMA using co-metabolic approaches. The full results from this project are available in Hatzinger et al., (2008). The key findings of that project are as follows: (1) the propanotroph *Rhodococcus ruber* EN425 is capable of degrading NDMA to innocuous products; including formate, nitrate, nitrite, methylamine, and carbon dioxide (Figure 1.1; Fournier et al., 2009); (2) biodegradation of NDMA from typical groundwater concentrations (e.g., 1-100 μg/L) to low part-per-trillion (ng/L) concentrations by *R. ruber* ENV425 is achievable (Figure 1.2; Fournier et al., 2009; Hatzinger et al., 2011); (3) similar propanotrophs capable of degrading NDMA are indigenous to other groundwater environments, and these organisms can be stimulated to degrade NDMA through the addition of propane and oxygen (Figure 1.3); (4) propane does <u>not</u> appear to be a significant inhibitor of NDMA biodegradation by many propanotrophs even though the reaction is cometabolic (Figure 1.4; Sharp et al., 2010); and (5) the presence of TCE and NDMA as co-contaminants can inhibit NDMA removal (Hatzinger et al., 2008; Hatzinger et al., 2011).

Results from batch experiments and a laboratory bioreactor study with the propanotroph *R. ruber* ENV425 revealed that NDMA treatment to levels of < 10 ng/L were achievable through biodegradation (Hatzinger et al., 2011; Fournier et al., 2009). In a membrane bioreactor (MBR) fed propane and oxygen and seeded with ENV425, effluent NDMA levels < 10 ng/L were consistently achieved for > 4 months from NDMA influent levels typical in contaminated groundwater (10 – 80 μg/L) (Hatzinger et al., 2011). The MBR was selected for the initial laboratory studies in the SERDP project to prove the concept that NDMA could be biologically treated to ng/L concentrations (this had not been previously shown). The advantages of this type of reactor design for laboratory studies included the following: (1) the absence of significant adsorption of NDMA to GAC or other media allowed mass balance calculations to be more easily performed, and (2) the membrane filtration of effluent allowed for complete retention of active biomass in the system, providing the best opportunity to demonstrate treatment below 10 ng/L of NDMA. However, an MBR is not the optimal design for cost-effective treatment of NDMA-laden groundwater at full-scale. Therefore, in the first phase of this ESTCP demonstration, a treatability study was conducted in which a bench-scale fluidized bed bioreactor (FBR) was tested for NDMA removal from water (See Section 3.2; Webster et al., 2009; Webster et al., 2013). The FBR is an efficient fixed-film bioreactor in which a high concentration of biomass is attached onto fluidized medium and has been widely used for the treatment of groundwater contaminated with a variety of compounds (see Section 2.1). Within the fluidized medium, biological treatment of the contaminated water occurs. In laboratory studies, the particular NDMA degrading microorganism, *R. ruber* ENV425, has shown to develop an extensive biofilm that was anticipated to be highly suitable for optimal performance in an FBR.

Figure 1.1 Metabolites produced during the oxidation of NDMA by *R. ruber* ENV425 after growth on propane (*from Fournier et al., 2009*).

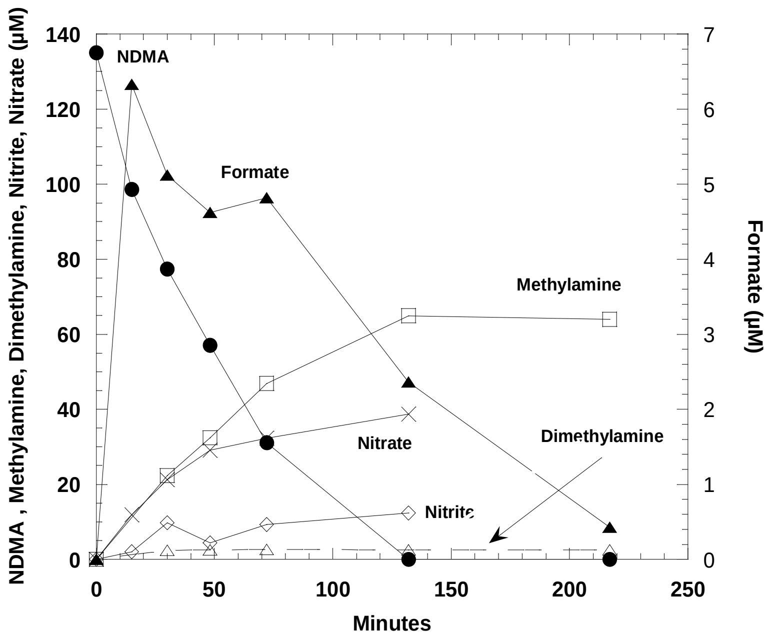


Figure 1.2 Biodegradation of NDMA by the propanotroph *Rhodococcus ruber* ENV425 in batch culture. Propane was added to the headspace of the reaction vessel. NDMA levels were below the PQL of 2 ng/L after 18 hr.

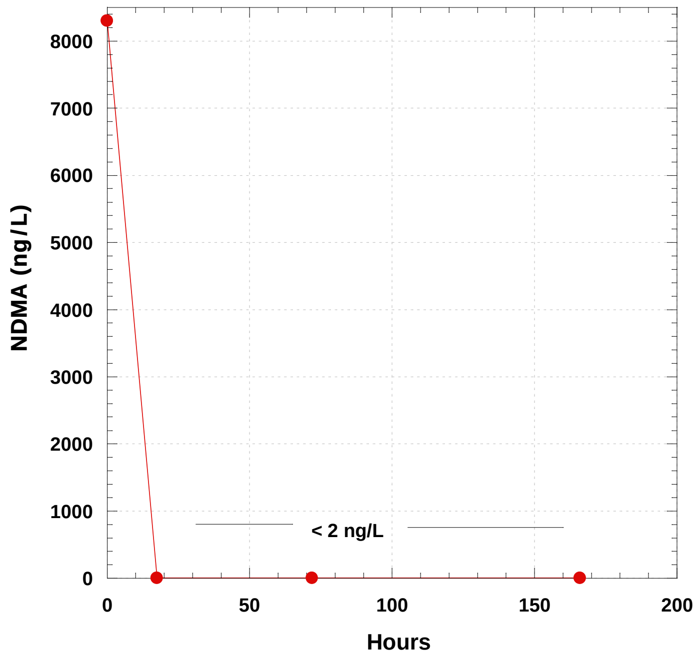


Figure 1.3 Effect of propane on the mineralization of ^{14}C-NDMA to $^{14}CO_2$ by the propanotroph *Rhodococcus ruber* ENV425. Propane added to the headspace of the reaction vessels stimulated NDMA mineralization rather than being inhibitory.

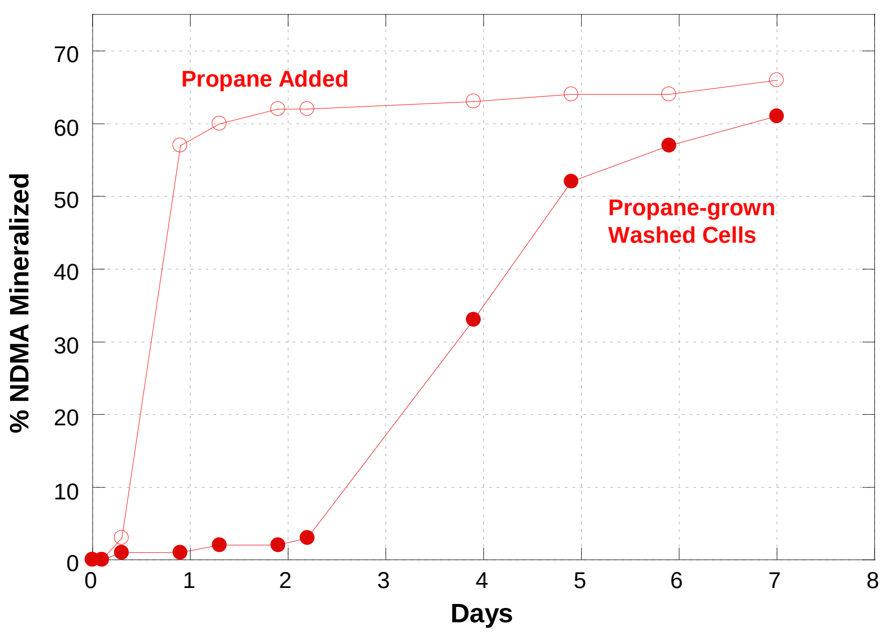


Figure 1.4 Percent mineralization of ^{14}C-NDMA to $^{14}CO_2$ in microcosms prepared with aquifer solids and groundwater from three different states (NJ, CO, CA). Microcosms were pre-incubated with propane and oxygen (propane) or oxygen only (unamended) for three weeks, then amended with 50 μg/L of NDMA. All propane-treated microcosms showed significant NDMA mineralization.

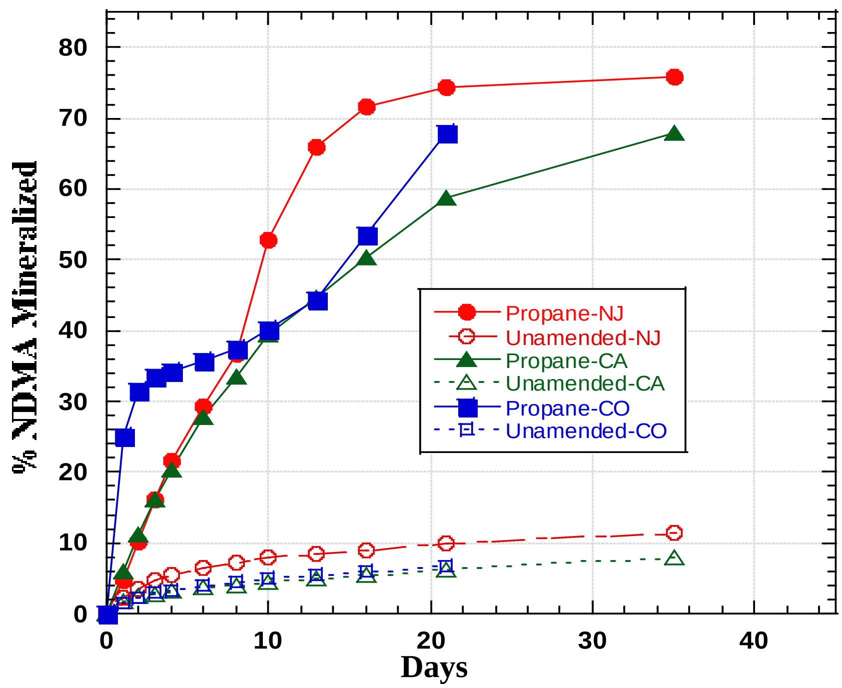
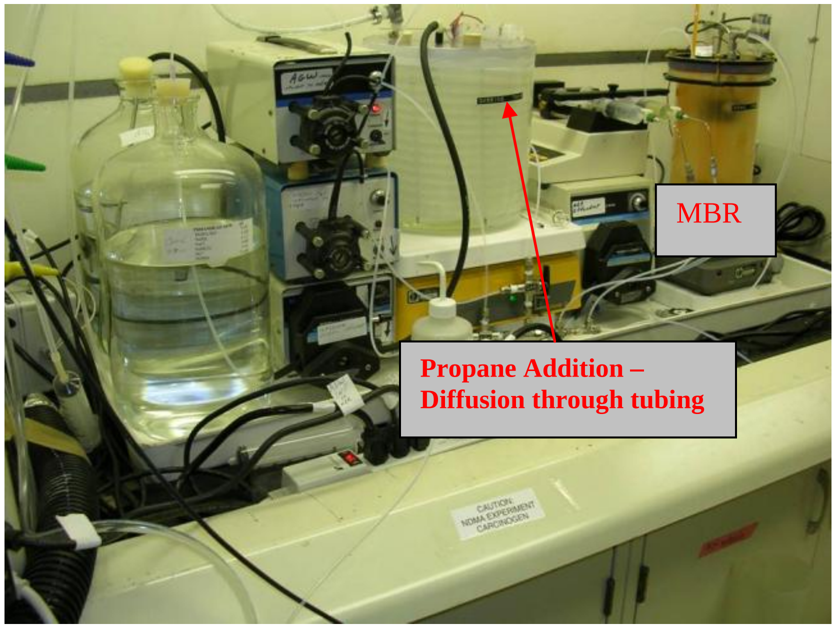
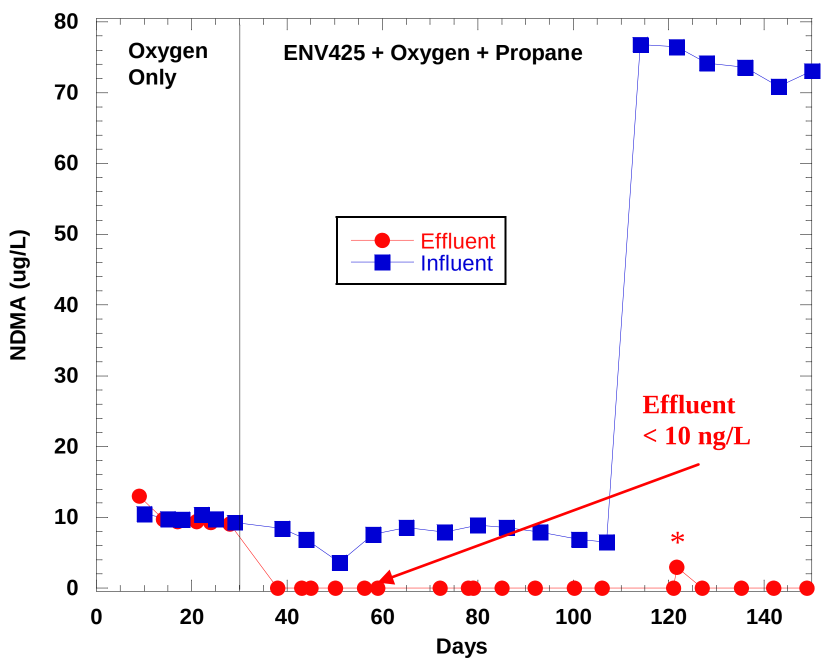


Figure 1.5 Laboratory propane-fed membrane bioreactor treating NDMA (top panel). Influent and effluent data from the MBR (bottom panel). All effluent points after culture inoculation were < 10 ng/L except that denoted with an *. (*from Hatzinger et al., 2011*).





1.2 Objective of the Demonstration

The objective of this pilot-scale demonstration is to evaluate the cost and performance of a biological fluidized bed reactor (FBR) for the treatment of NDMA in groundwater under actual field conditions. Based on results from a laboratory-scale FBR (Section 5.3; Webster et al., 2013), it is expected that the FBR technology will be appreciably cheaper than the current UV approaches for NDMA over a 30-year life cycle. Further corroboration of such findings from the laboratory FBR study is required at the pilot-scale level in the field. Pilot-scale operating performance and design parameters from the field FBR will be developed to accurately size a potential full-scale FBR remediation system for WSTF and other DoD facilities with NDMA contaminated groundwater.

1.3 Regulatory Drivers

Historically, NDMA was not thought to be a significant groundwater contaminant, so no federal MCL currently exists for drinking water in the U.S. However, according to EPA, a safe level of NDMA in drinking water based on lifetime *de minimus* risk calculations (< 10^{-6} risk of developing cancer) is only 0.7 ng/L (USEPA, 2013), which is below the current practical quantitation limit for the compound. Due to the carcinogenicity of NDMA, the California Office of Environmental Health Hazard Assessment (OEHHA) established a public health goal (PHG) for NDMA in drinking water of 3 ng/L (OEHHA, 2006). This is lower than the State of California's current *action level* for NDMA in groundwater, which is 10 ng/L (CDHS, 2008). Only three other compounds (of ~ 80 with regulatory action levels in California) are regulated at or below 10 ng/L (CDHS, 2008). The EPA also recently added NDMA to its current Contaminant Candidate List - 3 (CCL-3; USEPA, 2008), which is a possible step toward regulation under the Safe Drinking Water Act. At many military bases and installations, local government water agencies set the pump-and-treat discharge limits of NDMA. For example, NASA White Sands Test Facility (WSTF) in New Mexico was regulated at 10 ng/L of NDMA for discharge of treated groundwater for surface deposition for a number of years. As of September 2011, the New Mexico Environmental Department changed the NDMA concentration regulated by the discharge permit from 10 ng/L to 4.2 ng/L. The original objective of this study was to treat to 10 ng/L, but the system was later assessed to determine its ability to reduce the effluent NDMA concentrations below 4.2 ng/L. As the presence of NDMA in ground water aquifers continues to be discovered and potentially impacts drinking water sources, future State and Federal regulations will likely be enhanced further.

2.0 Technology

2.1 Technology Description

During this ESTCP project, the biodegradation of part-per-billion (µg/L) concentrations of NDMA was evaluated in a granular activated carbon (GAC) based FBR. Preliminary studies in Shaw's laboratory showed that NDMA can be consistently biodegraded in a bench-scale FBR (see Section 5.3; Webster et al., 2013). Treatment objectives to reduce NDMA at typical groundwater concentrations at WSTF (i.e., 1–20 µg/L) to below regulatory requirements for the facility (<10 ng/L) were demonstrated when the laboratory system was optimized. However, corroboration of the performance and design parameters under actual field conditions was required. Therefore, in this ESTCP demonstration, a FBR was tested for NDMA removal from groundwater at the WSTF under actual field operating conditions. FBR systems have been built by the Biological Reactor Group at Envirogen Technologies, Inc. at the full-scale (50 - 5,000 gpm) for treatment of several different contaminants in groundwater, including perchlorate, nitrate, and chlorinated solvents. Thus, a successful demonstration at the pilot scale could lead to the rapid employment of full-scale systems at DoD, NASA and/or commercial aerospace facilities with NDMA in groundwater.

The FBR is an efficient fixed-film bioreactor. It consists of a reactor vessel containing media with a high surface area (usually sand or GAC) to foster the growth of microbial biomass (Sutton and Mishra, 1994; USEPA, 1993). The high biomass achievable within the FBR bed makes it appreciably more efficient for water treatment than many other types of biological reactor systems (USEPA, 1993). This reduces the reactor size and, subsequently, the cost of treatment. The media bed is fluidized by passing influent groundwater through a distribution system at the bottom of the FBR vessel (Figure 2.1). This distribution system provides a consistent upflow velocity with a flow rate sufficient to achieve a 25-30% expansion of the media within the FBR (Figure 2.2). For this project, the FBR is inoculated with a known NDMA degrading propanotroph, *R. ruber* ENV425. Adequate quantities of cosubstrate/electron donor (i.e., propane) and nutrients are added to the reactor through a system water recycle line. Utilizing the propane and inorganic nutrients, the attached microorganisms perform an oxidation/reduction reaction in consuming the dissolved oxygen and propane. The NDMA is removed through cometabolism. As the microorganisms grow, the amount of attached microbes per media particle also increases. Since the microbes primarily consist of water, the volume of the microbe/media particle increases, but the specific density decreases (Figure 2.2). This allows the media bed to expand and fluidize further such that longer hydraulic retention times (HRTs) can be achieved for contaminant removal. The treated fluid flows into a submerged recycle collection header pipe and the effluent collection header pipe at the top of the reactor. A portion of the fluid exits the FBR system while the balance is recycled back to the suction of the influent pump. An in-bed biomass separation device controls bed height growth by physically separating biomass from the media particles. Typically, a bed expansion of 40-60% of the settled bed height is targeted. Any excess biomass that is separated from the media exits the system through the effluent collection system.

Figure 2.1 Schematic of fluidized bed bioreactor.

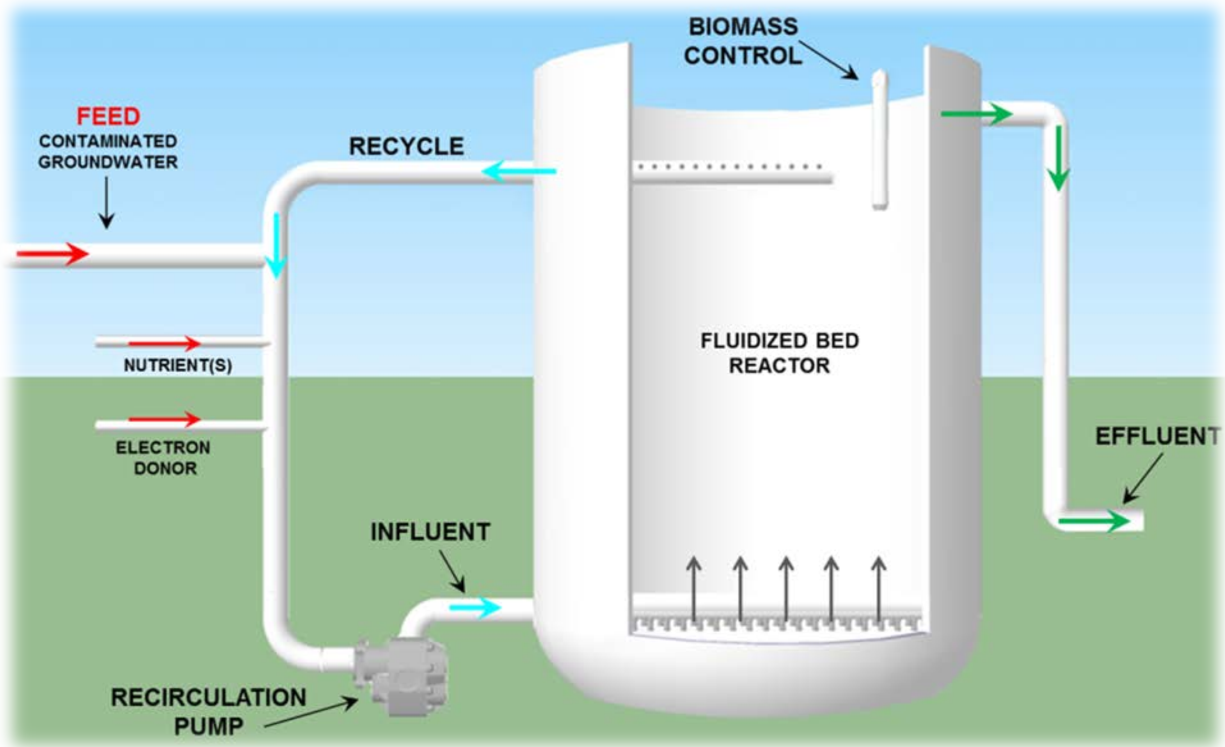
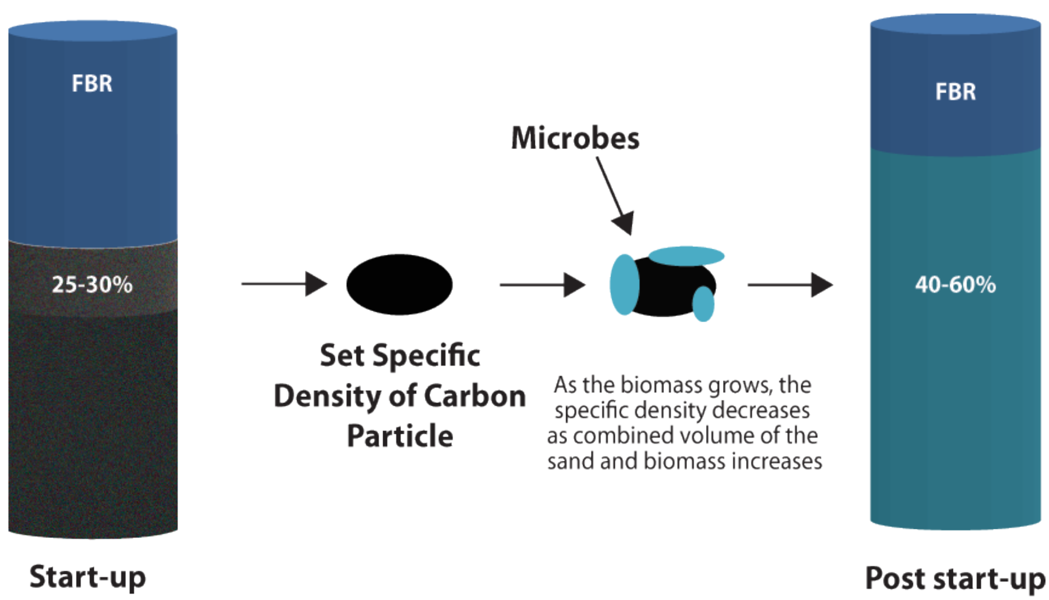


Figure 2.2 Hydraulic and biological expansion of media (*from Webster et al., 2009*).



2.2 Technology Development

The fundamental biological concept supporting this field demonstration is the utilization of aerobic cometabolism for degradation of an environmental pollutant. This concept is supported by extensive laboratory research and field testing. The first publications on cometabolic reactions and their potential applications for remediation date to the 1960s (Alexander, 1967), and scientific research was conducted on the cometabolism of many different compounds thereafter (Alexander, 1994 and references therein). The observation that methanotrophic bacteria are capable of dechlorinating TCE and other chlorinated ethenes and ethanes (Oldenhuis et al., 1989) and that this process can be stimulated *in situ* (Wilson and Wilson, 1985) resulted in the initial field testing of cometabolic degradation for chlorinated solvent remediation (Hazen et al., 1991; Semprini and McCarty, 1991). Since this time, cometabolic degradation of chlorinated solvents by phenol- and toluene-degrading bacteria has been examined in the field (Hopkins and McCarty, 1995; McCarty et al., 1998), and more recently, the application of propane-oxidizing bacteria for *in situ* treatment of chlorinated solvents (Battelle, 2001; Tovanabootr et al., 2001) and gasoline oxygenates (Steffan et al, 2003) has been successfully demonstrated at the field-scale. Cometabolic bioreactors have also been tested at the at the laboratory scale for chlorinated solvent remediation, primarily TCE (e.g., McFarland et al., 1992; Landa et al., 1994; Guo et al., 2001). However, full-scale application of such reactors has not generally occurred primarily because of difficulties with toxic intermediates of TCE (i.e., TCE-epoxide) causing excessive cell death, and because of inhibition of the primary substrate (generally methane) on the degradation of the compound of interest. Based on preliminary testing, these inherent issues with cometabolic degradation of TCE should be much less of a concern with degradation of NDMA, as toxic intermediates are not formed, and substrate inhibition is low with some strains.

The fluidized bed bioreactor is a mature technology that was originally developed beginning in the 1970s as a means to increase the efficiency of traditional packed bed reactors (USEPA, 1993; Sutton and Mishra, 1994). Full-scale FBR systems (50 – 5,000 gpm) built by the Shaw Environmental, Inc. Bioreactor Group (now Envirogen Technologies, Inc.) are presently operating at several DoD and DoD-contractor facilities to remove perchlorate (and nitrate) from groundwater (Hatzinger, 2005). Currently, there are five full-scale FBR systems that are treating more than 9 million gallons of perchlorate-contaminated groundwater per day. One system is located at the Aerojet facility in Rancho Cordova, CA. The facility treats up to 5,000 gpm of groundwater using four fluidized bed reactors (FBR). A second FBR system is located in Karnack, TX at the Longhorn Army Ammunition Plant (LHAAP) where the groundwater is contaminated with volatile organic compounds (VOCs) and perchlorate from past operations at the site (Figure 2.3A). A full-scale FBR (5-foot diameter) system with the capacity to treat 50 gpm is currently operating as designed. A third FBR system treating perchlorate laden water has been constructed at the McGregor Naval Weapons Industrial Reserve Plant (McGregor TX) and operates at 100 gpm. A fourth FBR system consists of nine, 14-ft diameter FBRs located at a site in Henderson, Nevada. These reactors are sequenced such that the influent water flows through five sand-based FBRs followed by four GAC-based FBRs for polishing. This system treats approximately 1000 gpm of influent groundwater contaminated with perchlorate, chlorate, and nitrate (Figure 2.3B). The fifth full-scale system is located at Jet

Propulsions Laboratory in Pasadena, CA, treating approximately 300 gpm of water with perchlorate concentrations of up to 500 µg/L (Figure 2.3C). Based on the successful installation and operation of these units, the technology is mature and potentially capable of effectively treating NDMA-laden water. Moreover, a new system presently being installed in Rialto, CA is permitted to produce drinking water from perchlorate-laden groundwater.

Figure 2.3 Three full-scale FBR installations.

The key challenges of this ESTCP demonstration were to (1) develop an FBR feed system capable of effectively and safely supplying propane and oxygen, and (2) optimize the FBR technology for the treatment of NDMA to ultra-low concentrations. To date, a field-scale propane-fed FBR has never been built or tested. With respect to the relevant microbiology, it has been demonstrated that NDMA can be biodegraded by a wide variety of propane-oxidizing bacteria, and that these strains can readily achieve NDMA levels below 10 ng/L in both batch experiments and in a laboratory bioreactor operated continuously for several months (Fournier et al., 2009; Hatzinger et al., 2008, 2011). In addition, it has been determined that NDMA degradation by ENV425 follows a mixed denitration/demethylation pathway producing low concentrations of innocuous products including methylamine nitrite, nitrate, and methanol (Fournier et al., 2009). The strain also mineralizes significant quantities of NDMA to carbon dioxide (> 60%). During the laboratory phase of this ESTCP study, at a 20-30 min hydraulic residence time (HRT) using a bench-scale FBR system, effective removal of 10-20 µg/L of NDMA to levels less than 10 ng/L was demonstrated, suggesting that this approach has promise at the field scale. (Section 5.3; Webster et al., 2013). Thus, the FBR is a mature technology and laboratory data to date suggest that this technology is applicable to treat NDMA to ng/L concentrations potentially at both the pilot- and full-scale.

2.3 Advantages and Limitations of the Technology

The main advantages of utilizing an FBR for NDMA treatment are:

- Potentially reduced operating costs compared to traditional physical/chemical treatment technologies such as UV irradiation;
- Near complete destruction of the NDMA via a biological process with no harmful intermediates formed;
- Effective recovery from feed and power loss to the treatment system;

- An effective and safe means to provide delivery of both oxygen and propane gas to these systems is needed and has been designed into such treatment systems.
- Potentially capable of treating multiple contaminants in the same reactor; and
- Limited space requirements for a complete treatment system.

Technical risks and limitations inherent to the system include:

- NDMA microbiological degradation in the laboratory has been demonstrated during the treatability study using a bench-scale FBR. Although it has been determined that laboratory bioreactor designs (MBR and FBR) could effectively treat NDMA to low concentrations, treatment at field scale and under field conditions has not been proven.

- Operator attention to the FBR may be at least as much as physical/chemical treatment technologies such as UV irradiation.

- Influence of co-contaminants on NDMA degradation. NDMA treatment may be inhibited by chlorinated organics, such as trichloroethylene if concentrations are high enough. These compounds can easily be removed from the water prior to entering the FBR (e.g., via air-stripping).

- Biomass solids are generated which may require additional filtration prior to the water being reinjected or discharge to surface water.

Based on this successful demonstration, the DoD will have a widely applicable *ex situ* remediation approach for NDMA. Ultraviolet (UV) treatment is presently the primary practical method used to remove NDMA from groundwater. Although this technology is effective, it is also very expensive. For example, Aerojet (Sacramento, CA) currently spends nearly $400,000 per year in electrical costs only to operate a UV system for a 5,000 GPM groundwater flow (Fennessy, 2007). Operational costs for the FBR treatment system include chemical and electrical costs. Based on the low concentrations of NDMA (low contaminant loading rates), these operational costs are expected to be a fraction of the amount observed for a UV system (see Section 7.3). In that further state and/or federal regulations for this carcinogen are likely in the future, it is important to evaluate potentially less expensive treatment options for NDMA. This demonstration assessed a biological treatment approach with the potential to be both effective and economical. Such a discovery provides both a cost- and environmental-benefit to a number of DoD installations and contractors (i.e., WSTF, Edwards Air Force Base, Aerojet, etc.) that implement this technology.

3.0 Performance Objectives

Performance objectives are provided in Table 3.1.

Table 3.1 Performance objectives.

Performance Objective	Data Requirements	Success Criteria	Results
Quantitative Performance Objectives			
Determine NDMA degradation effectiveness in FBR at start-up	•Initial feed and effluent NDMA concentration data during first month of operation	•Reduction of NDMA concentrations from µg/L to low ng/L (<100 ng/L)	•NDMA was reduced to below 100 ng/L at a 60 minute HRT by the fourth week after inoculation
Assess pilot-scale FBR ability to treat NDMA to below regulatory limits (10 ng/L, later to 4.2 ng/L)	•Feed and effluent NDMA concentration data at different HRTs by EPA Method 607 and High-Resolution Mass Spectrometry (HRMS) by Southwest Research Institute (SRI)	•Reduction of NDMA concentrations to less than 10 ng/L (then 4.2 ng/L) at a HRT less than 30 minutes •Meet 95% completeness	•At an HRT of 10 minutes, NDMA was reduced to less than 10 ng/L, and to below 4.2 ng/L at a 20 minute HRT. •The 95% completeness measurement was achieved, with completeness at 98% for the NDMA samples
Effects of interruptions in plant operation	•Feed and effluent co-contaminant concentration data at minimal HRT upon shutdown/restart	•Reestablishment of FBR performance to less than 10 ng/L after feed restart	•Within 24 hrs to 4 days after feed restart, NDMA was reduced to less than 10 ng/L
Effects of co-contaminants on NDMA treatment	•Feed and effluent co-contaminant concentration data at minimal HRT	•< 100 ng/L in effluent during co-contaminant addition, •Any reduction in co-contaminants	• At the 10 minute HRT, system achieved consistent removal below 10 ng/L but not 4.2 ng/L. • Some reduction in CFC 11 & TCE was observed
Assess pilot-scale FBR treatment of DMN	•Feed and effluent DMN concentration data at different HRTs. •High-Resolution Mass Spectrometry (HRMS) by Southwest Research Institute (SRI).	•Reduction of DMN concentrations to less than 10 ng/L	• DMN was consistently reduced to < 10 ng/L at a 20 and 30 min HRT. • < 10 ng/L DMN also was achieved at a 10 min HRT except during feed challenge
Qualitative Performance Objectives			
Ease of use	•Feedback from field technician on usability of technology and time required	•A single field technician able to effectively take measurements safely	• System monitored by one field engineer effectively
Reliability	•Uptime of system. Mechanical issues •Daily measurements of operational data	•Greater than 90% uptime •Ability of electron donor system to consistently operate	•Uptime was 94% • No issues with the delivery of the electron donor were observed
Reduction of treatment costs	•Feed flow, oxygen addition rates, and propane addition rates	•Minimization of HRT and gaseous addition rates	•At 20 minute HRT with oxygen addition rate of 176 mg/min and a propane addition rate of 35 mg/min (28.6 mg C/min)

3.1 ENV425 Adaptation in FBR upon Start-up

During the first month of FBR start-up and operation, the propanotroph *Rhodococcus ruber* ENV425 was allowed to establish and grow on the GAC in the reactor under controlled conditions. Initially, the FBR was loaded with GAC only, and site water was fed through the reactor until NDMA breakthrough occurred. After the abiotic removal of NDMA was complete based on equivalent influent and effluent NDMA concentrations (~ 83 days), ENV425 and nutrients were added to the FBR in recycle mode. The FBR was maintained in recycle for a 7-day period, with propane and oxygen being added continuously at rates shown to be effective in the bench-scale test. With evidence of oxygen uptake and bed growth, the FBR received forward feed flow at a 60 min HRT on Day 90. Degradation of NDMA was clearly evident during this initial Phase (~ 25 Days), suggesting that ENV425 was forming a biofilm on the GAC media and removing NDMA from the influent water.

<u>3.1.1 Data Requirements</u>

Inlet and effluent NDMA analyses were conducted over the first month of operation after ENV425 inoculation to ensure that ENV425 was biodegrading NDMA under site geochemical conditions. The analysis of NDMA in the influent and effluent of the FBR was conducted by the Southwest Research Institute (SRI), the analytical laboratory contracted to perform NDMA analysis for the discharge permit requirements at WSTF. Two different methods were performed; EPA method 607 (http://water.epa.gov /scitech/methods/cwa/organics/upload/2007_07_10_methods_method_organics_607.pdf), which had a 5 ng/L method detection limit (MDL) and a high–resolution mass spectrometry (HRMS) method developed specifically for NASA to provide lower detection limits (0.2 ng/L MDL; See section 5.6).

In addition, some samples were split and analyzed by a second laboratory using EPA method 521 (0.28 ng/L MDL; http://www.epa.gov/microbes/documents/m_521.pdf) to confirm the analyses performed by SRI. Comparisons are provided in Section 6.1.2. Water chemistry parameters (pH, temperature, dissolved oxygen and propane, anions, volatile organic contaminants, and total suspended solids) were also analyzed across the FBR to provide supplemental information on the system performance. Such testing was also used to confirm that site water chemistry characteristics were not inhibitory to ENV425, as determined in the laboratory testing phase. The height of the FBR bed within the FBR was also measured to determine of bed growth was occurring as a measure of cell biofilm formation.

<u>3.1.2 Success Criteria</u>

Over the first month of system operation, the system was operated to allow ENV425 to attach to the GAC media and begin growth, and ideally to achieve less than 100 ng/L of NDMA in the effluent of the FBR by the end of the treatment phase form an influent value of ~ 1 μg/L. This level of treatment served as a baseline from which finer adjustments in propane, oxygen, and nutrient addition to the FBR occurred to allow for further improved NDMA removal. Reduction of NDMA concentrations from low µg/L to low ng/L levels indicated that treatment objectives were met, and that constituents in site groundwater were not inhibitory to ENV425. Results demonstrated that NDMA was degraded from ~1 µg/L down to ~ 10 ng/L within 25 days after inoculation. Success criteria were met. Bed growth

was also apparent during this phase (from ~ 85 to 90 inches), confirming cell attachment and biofilm formation on GAC media as was observed in the laboratory pilot study.

3.2 Assess Pilot-Scale Ability to Treat NDMA to Below Regulatory Limits

The effluent regulatory concentration for NDMA in groundwater at the White Sands Test Facility (the site chosen for the demonstration; See Section 5.0) was originally 10 ng/L when the demonstration began. Subsequently, due to permit changes, this limit was decreased to 4.2 ng/L. The original objective was to meet the 10 ng/L limit, however it was also desirable to meet the 4.2 ng/L as a treatment goal throughout the field demonstration. A 10 ng/L notification level for NDMA has been established by the California Department of Public Health (CDPH), so this concentration is relevant in California as well as New Mexico.

3.2.1 Data Requirements

Operation of a GAC based FBR inoculated with the propanotroph *R. ruber* ENV425 continued through start-up to steady-state operation. The analysis of NDMA in the influent and effluent of the FBR was conducted by the Southwest Research Institute (SRI) as described in Section 3.1.1. In addition, some samples were split and analyzed by a second laboratory (Weck Laboratories, Inc.) using EPA method 521 (0.28 ng/L MDL) to confirm the SRI analyses.

3.2.2 Success Criteria

The reduction of NDMA concentrations from ~ 1 µg/L in the influent to less than 10 ng/L, and later to < 4.2 ng/L when the WSTF discharge permit requirements changed (see Section 1.3), was indicative of successful treatment. An HRT of less than 30 minutes to achieve such NDMA treatment is expected to be more cost-effective at full-scale than current UV systems, thus the objective was to achieve consistent effluent concentrations of < 10 ng/L with an HRT of 30 minutes or less. Optimization of the treatment process occurred via analysis of FBR feed and effluent NDMA concentrations. Reductions in hydraulic residence time (HRT) were conducted while optimizing the oxygen and propane addition rates. Effluent NDMA concentrations below 10 ng/L were consistently achieved at HRTs of 10-30 minutes, and NDMA levels < 4.2 ng/L were consistently achieved at HRTs of 20-30 minutes, but not at an HRT of 10 minutes. Success criteria for NDMA treatment were met.

In collecting and analyzing the NDMA data for this study, it was essential that the sampling, shipping, and analytical procedures were closely followed. Based on the samples collected and analyzed for NDMA, the planned 95% completeness success criteria were achieved. From the samples collected and analyzed for NDMA, the percent of completeness achieved was 98%. Through quality control sample analysis, contamination of the samples was not observed and precision was confirmed for the laboratory performing the NDMA analysis.

3.3 Effects of Interruptions on FBR Operation

Challenge experiments were conducted to determine the ability of the FBR technology to rebound from feed flow interruption, system shutdowns, and propane and nutrient feed

interruptions. For the feed flow interruption, the FBR system remained in recycle mode so that the media bed remained fluidized. Oxygen and propane continued to be added to maintain microbial growth. The feed shutdown mimicked a situation in which a groundwater pump failed or forward flow to the FBR was otherwise interrupted. The experimental feed shutdown was conducted for 28 days (Days 287-315). This experiment lasted longer than anticipated due to required maintenance of the UV system, causing the planned two week shutdown to be extended two extra weeks. A number of unplanned feed shutdowns also occurred, primarily due to issues with the onsite UV system. During unplanned shutdowns, no influent water was provided to the FBR system for 1-5 day periods. The system was placed in recycle mode during these periods.

A total system shut down experiment (i.e., with no water recirculated through the FBR) was not initially planned, but power outage to the system and a complete system shut down due to equipment failure occurred on a few occasions. Pump 102, which fluidized the FBR, failed on Day 130 and the system was shut down for approximately four days while a new pump was acquired and installed. On Day 185, a lightning strike caused a power outage to the building and led to the system being shut off for one day. Several other power outages due to lightning occurred during the 30 minute HRT demonstration phase. The system was restarted when power was available to the mid-plume plant. Other power shut downs of the system occurred over Days 347-354, primarily due to a tripped breaker caused by a malfunctioning air compressor. The system experienced a complete shut down for three days starting on Day 351 until the air compressor was repaired.

The feed of both propane and inorganic nutrients was shut off on Days 270-279 to evaluate the effects of limitation of cometabolic substrate and growth nutrients on NDMA treatment. This experiment was designed to elucidate how resilient the system was to interruptions in the supply of these necessary substrates for cell growth in the FBR.

3.3.1 Data Requirements

NDMA analyses were conducted as described in Section 3.2.1 to determine the rebound in treatment of the FBR technology after the challenge studies. Influent and effluent NDMA analyses were conducted to determine the time required for effluent NDMA concentrations to return to less than 10 ng/L (or average value achieved prior to shut-down). Analysis of anions, DO, propane, pH, temperature, ammonium, phosphate, and bed height were also performed before and after these shutdown phases.

3.3.2 Success Criteria

For both the interruption of feed flow and total system shut-down, re-establishment of FBR performance to less than 10 ng/L of NDMA at the plant effluent within 24 hours of system restart was targeted. Detailing exact points of recovery was not always possible, as sampling after unplanned feed and system shutdowns was often not scheduled immediately after the occurrence of the event. In general, the system demonstrated complete recovery to less than 10 ng/L in 24 hrs to 4 days. During the 20-30 minute HRT, effluent concentrations < 4.2 ng/L of NDMA were observed consistently upon system restart.

For the feed shutdown occurrences (both unplanned and planned), the results were as follows:

- On Day 195, the system feed was restarted after a 5 day unplanned interruption due to maintenance on UV system, sampling occurred 24 hours after the restart at a 30 minute HRT and NDMA in the effluent was < 4.2 ng/L.

- After the system feed was shut down for 28 days (Days 287-315), flow was reinitiated at an HRT of 10 minutes, and sampling was conducted five days after restart. NDMA was detected at < 10 ng/L after 5 days. For the next 20 days, the NDMA effluent approached 4.2 ng/L, but did not fall below this value until 25 days after feed restart. However, as noted, the HRT during this phase was only 10 minutes.

For the total system shutdown experiments, the results were as follows:

- On Day 130, after the system had been completely shut down for four days due to pump failure (i.e., no fluidization of the bed, propane flow, or oxygen flow), it took ~ 18 days after system restart to achieve NDMA below 10 ng/L at a 40 minute HRT. It should be noted, however, that this was very early in the project, and the system was still undergoing significant bed expansion, so there was very little biomass inventory in the FBR at this time of the pump failure.

- On Day 186, after the system was shut down for one day due to power outage caused by lightning, the system recovered within 24 hours with NDMA < 4.2 ng/L.

- On Day 354, at a 10 min HRT, the system was shut off for three days due to issues with the air compressor and breakers. Sampling occurred three days after system restart, and the NDMA in effluent was 9.7 ng/L. The effluent was detected at 4.0 ng/L on Day 340, which was the last sampling event prior to issues with the air compressor.

For the challenge study in which the propane and nutrient feeds to the FBR were shut off for 9 days (Days 270-279) during operation at a 10 minute HRT, the NDMA only increased slightly from 6.8 ng/L on Day 270 to 8.8 ng/L on Day 279, from an influent concentration of ~ 1 μg/L. The effluent NDMA concentration was < 4.2 ng/L by Day 286.

Overall, the FBR proved to be remarkably resilient to upsets in influent flow or propane/nutrient amendments.

3.4 Effects of Co-Contaminants on NDMA Treatment

The presence of chlorinated solvents as co-contaminants may have an inhibitory effect on the treatment of NDMA by the propanotroph *Rhodococcus ruber* ENV425 (Hatzinger et al., 2011). Initially, the FBR feed water passed through an air stripper to remove TCE, Freon-113 (1,1,2-trichloro-1,2,2-trifluoroethane), and CFC-11 (trichlorofluoromethane) as primary co-contaminants. After the FBR had operated at steady-state while meeting the

NDMA effluent target goal, the air stripper was bypassed and the feed water with co-contaminants was introduced to the FBR (Days 350-377). This experiment simulated an upstream co-contaminant removal process failure (i.e., air stripper failure). Such a study assisted in demonstrating the effects on NDMA removal within the FBR with the presence of the co-contaminants.

3.4.1 Data Requirements

Removal of both NDMA and the targeted co-contaminant(s) by the FBR were measured via EPA Method 607 (NDMA) and by HRMS (NDMA) and EPA Method 8260 (VOCs). FBR feed and effluent co-contaminant analysis were conducted and correlated with NDMA treatment. General water chemistry analysis was also conducted to ensure that steady-state operation continued for the system.

3.4.2 Success Criteria

Treatment of NDMA to less than 100 ng/L in the presence of site co-contaminants was the objective. If less than 10 ng/L of NDMA could be maintained in the effluent of the FBR, it would be unnecessary to restart the process of bypassing the co-contaminants. NDMA in the FBR effluent was detected at < 10 ng/L during the 10 minute HRT in the presence of co-contaminants except for one data point (NDMA was at 14 ng/L). Some reduction in Freon 11 was observed during this experiment, but that likely reflects adsorption to the GAC matrix. TCE was reduced to < 1 μg/L, which may have been the result of a combination of adsorption and biodegradation. No inhibition of NDMA treatment was observed during the demonstration due to presence of co-contaminants, specifically TCE. Eight days after the feed bypassed the air stripper, the effluent NDMA was below 10 ng/L, but did not decline below 4.2 ng/L at the 10 minute HRT. However, the objectives were met.

3.5 Assess Pilot-Scale FBR Treatment of DMN

In addition to NDMA and several VOCs, N-nitrodimethylamine (DMN) was also present in the WSTF groundwater from former rocket engine testing activities at approximately 0.6 μg/L. Although not a primary objective of this study, the treatment of DMN by the FBR was documented. Previous studies in our laboratory (Fournier et al., 2009) revealed that ENV425 was capable of degrading both DMN and NDMA during growth on propane.

3.5.1 Data Requirements

DMN was detected via HRMS by SRI during analysis of NDMA as described in Section 3.1.1.

3.5.2 Success Criteria

Treatment of DMN to < 10 ng/L in the FBR at an HRT value of 20 to 30 minutes was the objective. The treatment objective was met. DMN was treated to ≤10 ng/L from Day 97 to Day 270, when the propane and nutrient feed was shut off. DMN increased to 46 ng/L by Day 279 when the gas and nutrient addition was reinitiated. The concentration remained at 47 ng/L on Day 286, but declined thereafter, falling to < 10 ng/L from Day 320 to the end of the study on Day 377.

3.6 Ease of Use

The ability to operate the pilot-scale equipment with minimal operator attention was evaluated.

3.6.1 Data Requirements

Daily and weekly operating records were maintained to determine hours of operation and maintenance required. The use of oxygen and propane in one unit provided safety challenges that were engineered into the system. These engineering requirements were evaluated to determine their operational and safety effectiveness.

3.6.2 Success Criteria

System operation by one technician. Operator attention of about ten hours per week (2-4 hours per day, 3 times a week) was considered ideal for the pilot-scale system. The criteria were generally met during the demonstration.

3.7 Reliability

Even though this plant operated as a pilot-scale system, it was imperative that operational and mechanical upsets were minimized to ensure that the technology maintained uptime reliability. Uptime reliability was defined in terms of performance as well as mechanical operability (although these two variables are not mutually exclusive).

3.7.1 Data Requirements

After steady-state operation was achieved, manual records were maintained to document the level of uptime for the system in meeting the performance objectives and mechanical operability. Mechanical problems were documented with their cause, the solution to repair the issue, and the time required between the initial failure and final resolution.

3.7.2 Success Criteria

Greater than 90% uptime reliability was the target goal. For instances when intentional interruptions or manual changes in system operation were encountered, such breeches in reliability were not incorporated into the system uptime calculation. The largest upsets to the system were caused by equipment failure from the air compressor and a fluidization pump (pump 102). Power outages caused by lightning storms or other issues also caused system downtime. A third shut-down in system operation was caused by required maintenance to the UV system, which resulted in interrupted feed flow to the FBR. A 94% uptime was achieved, even when taking into account the system downtime that was not related to the FBR (i.e., power issues and UV system maintenance), so the system met our criteria for reliability.

3.8 Reduction of Treatment Costs

The cost-effectiveness of the technology is directly correlated to the system HRT and the necessary chemical addition requirements. The system HRT was reduced as low as possible over the course of the study to determine the point where $\geq$99% removal of the NDMA occurred (1 μg/L to < 10 ng/L and later 99.6% to < 4.2 ng/L with more stringent WSTF discharge requirement). By determining the maximum elimination capacity

achievable, direct scale-up to the full-scale estimate could be calculated. From such data, the size of the full-scale treatment plant could be calculated and the cost-effectiveness of the capital investment of the technology determined.

The addition of chemicals to the system directly affects the system operating costs. Based on the determined operating costs, in conjunction with the estimated capital costs, a life-cycle cost for a full-scale treatment plant has been determined.

3.8.1 Data Requirements

In maximizing the HRT, feed and effluent NDMA/general water chemistry were measured to maximize performance at the minimum nutrient, propane, and oxygen addition rates. These addition rates were monitored daily by the field technician, with adjustments instituted to optimize performance.

3.8.2 Success Criteria

Testing was conducted to minimize nutrient/propane/oxygen addition rates while continuing to achieve less than 4.2 ng/L NDMA at the effluent of the FBR. Every attempt was made to minimize these chemical addition rates, the system electricity requirements, and operator attention/maintenance. A 20 minute HRT produced optimal conditions for the FBR system to meet the most stringent WSTF discharge requirement for NDMA of <4.2 ng/L. So, the optimal operating parameters of the FBR for reducing NDMA in groundwater to below 4.2 ng/L are:

- 20 minute hydraulic retention time
- An oxygen addition rate of 176 mg/min
- A propane addition rate of 35 mg/min (28.6 mg C/min)
- A diammonium phosphate addition rate of 35 mL/min at 110 mg/L
- A urea addition rate of 36 mL/min at 352 mg/L

Additional reductions in gas addition may be possible for a full-scale FBR system, resulting in a further decrease in operational costs. The pilot-scale study demonstrated that the NDMA could be removed up to 99.8% under the optimal operating parameters.

4.0 Site Description

4.1 Site Selection

Site selection entailed an initial review of the conditions at two NDMA-contaminated facilities, WSTF and Aerojet Corporation (California). Site data evaluated for each candidate location included: (1) basic groundwater geochemistry, (2) NDMA contaminant concentrations, (3) presence of co-contaminants, (4) presence of basic infrastructure for an *ex situ* demonstration (e.g., existing pump-and-treat infrastructure, wells, electric, roads, etc.), and (5) available on-site support. WSTF was initially approached because of their extensive NDMA contamination issues and immediate plans to develop a new treatment plant, the "Mid-Plume Interception and Treatment System (MPITS)". Subsequent analysis of the WSTF water and the demonstration of the ability of ENV425 to degrade the NDMA-laden water with a bench-scale FBR indicated that the site was an ideal candidate for the pilot-scale study.

During bench-scale microcosm and FBR studies, water from the WSTF was evaluated and the ability of ENV425 to degrade NDMA in that site-water environment was readily demonstrated (Section 5.3). Based on the successful fluidized bed bioreactor laboratory-scale results treating synthetic and actual NASA WSTF to low ng/L concentrations (Figure 5.6; Section 5.3), the "Go" decision to the pilot-scale demonstration was authorized by ESTCP.

WSTF was chosen as the site location for the demonstration of the pilot-scale FBR because (1) they had an extensive groundwater plume with high levels of NDMA and typical co-contaminants found at NDMA sites from rocket testing applications (i.e., TCE and Freon-113), (2) they were installing a full-scale UV system which could provide an excellent comparison to the pilot-scale FBR plant at the demonstration site, (3) the site had the available infrastructure to host the pilot project, and (4) the WSTF management was interested in participating in the ESTCP demonstration and had on-site contractors to assist with system installation and non-routine maintenance issues (e.g., pump replacement).

4.2 Site Location and History

NASA WSTF is located 12 miles east of Las Cruces, New Mexico, six miles north of U.S. Highway 70 on the western flank of the San Andres Mountains and on the eastern edge of the Jonada del Muerto Basin. The facility is approximately 28 square miles situated on the U.S. Army's White Sands Missile Range. Historically, this test facility evaluated rocket engines, space flight components, and rocket propulsions systems. More recently, it continues to test such systems, but also serves other testing functions for NASA including materials assessment, hazard assessments, space flight system testing, and launch and landing system testing.

The pilot-scale FBR was located at the newly constructed full-scale MPITS building (Figures 4.1-4.3). After numerous discussions with WSTF management, this site was chosen because of the high concentrations of NDMA at the mid-plume location, the availability of the necessary access roads and utilities, the security of having the pilot system inside of a building housing the full-scale treatment plant, and the ability to directly

compare the new full-scale plant treatment effectiveness with the pilot FBR operation. The MPITS is designed to treat 125 gpm of flow from various extraction wells located in the mid-plume area. Treatment of the water involves the use of an air stripper for volatile organic contaminants (primarily Freon-113, CFC-11 and TCE) followed by a low pressure lamp UV photolysis system for NDMA treatment (Figures 4.1 and 4.2). The pilot FBR was located next to the air stripper, allowing feed water to the FBR to originate from either before or after the air stripper (Figure 4.3).

The demonstration study with the pilot-scale FBR began on March 8, 2012. At this point the MPITS construction was complete and all startup issues for MPITS were resolved.

Figure 4.1 NASA MPITS system process flow diagram.

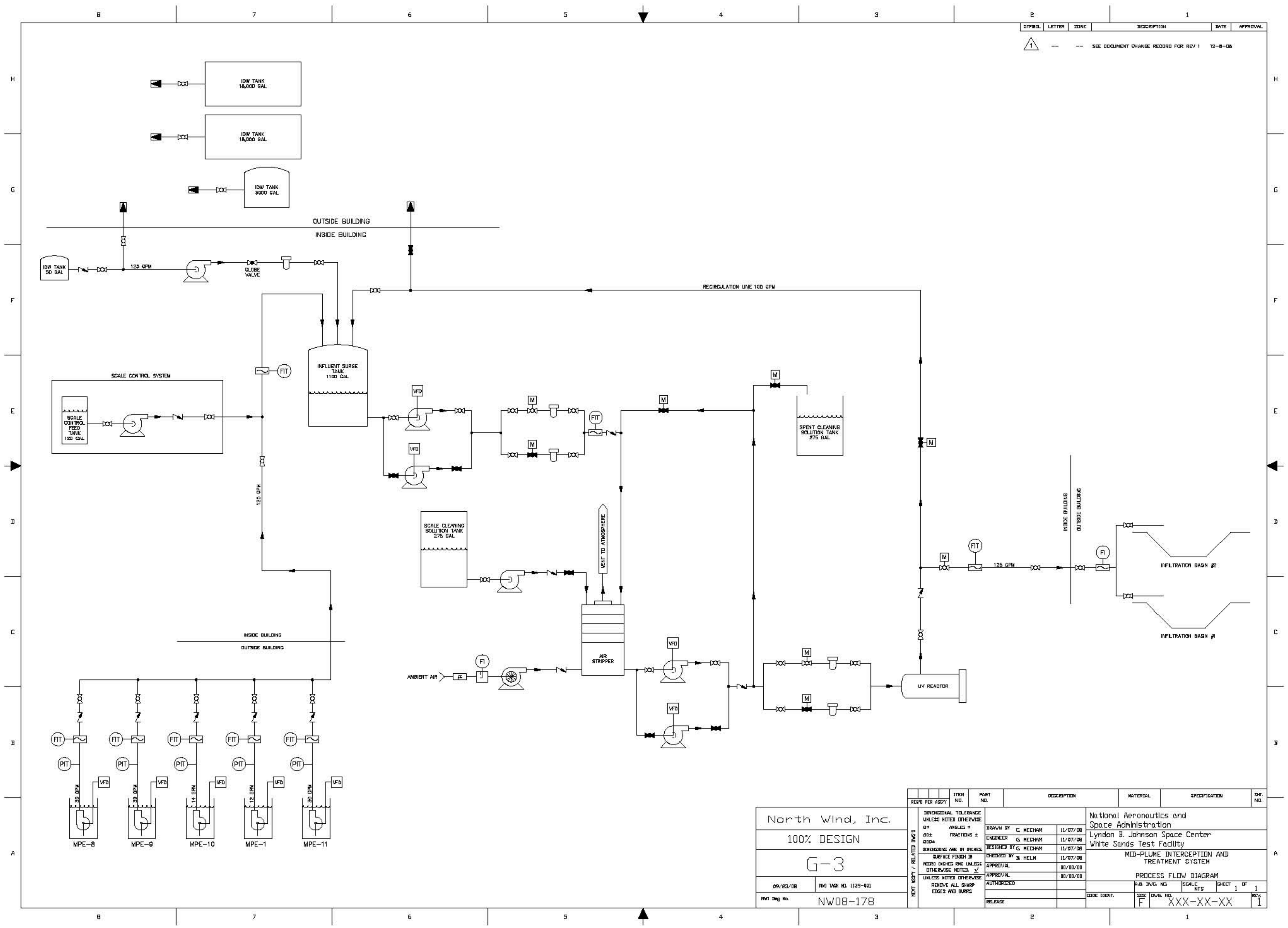
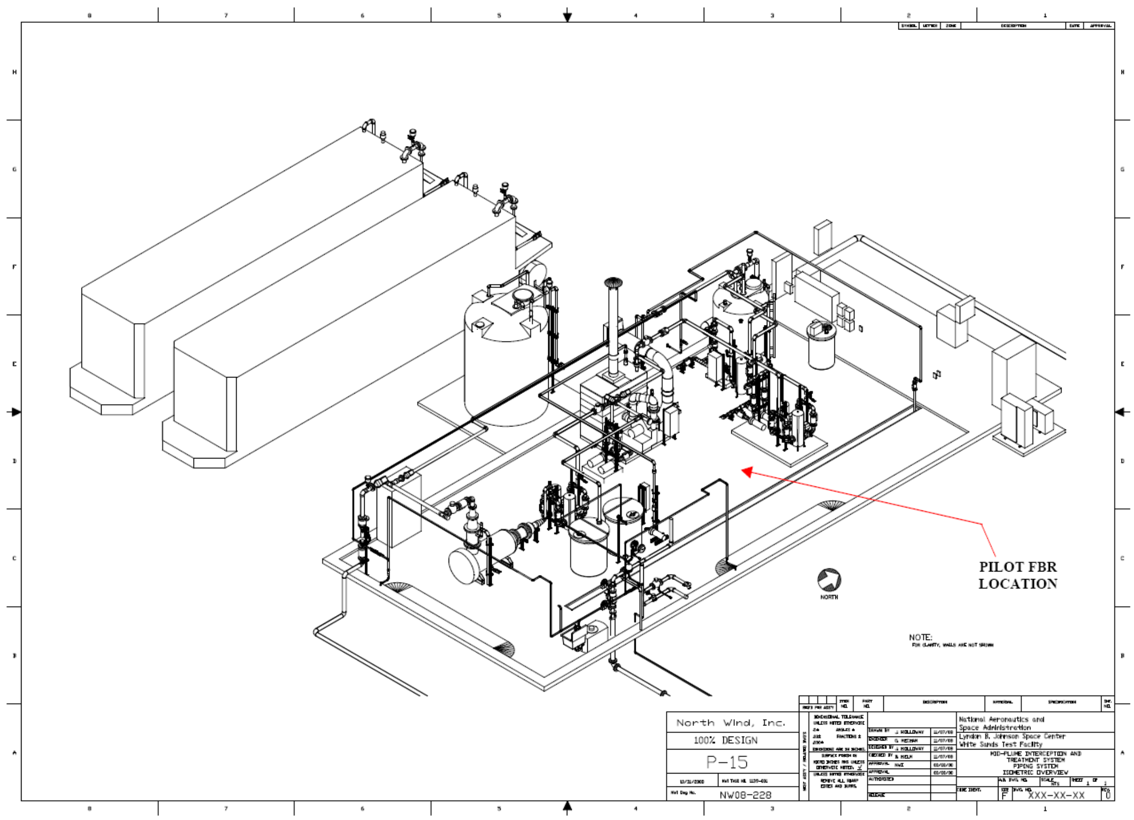


Figure 4.2 NASA WSTF MPITS UV System.

Figure 4.3 NASA WSTF MPITS with Pilot FBR Locale.



4.3 Site Geology/Hydrogeology

WSTF is in the Mexican Highland Section of the Jonada del Muerto Basin and within the Rio Grande Rift Zone. WSTF is located along the western flank of the San Andres Mountains, with the uppermost alluvial layers consisting of silt, sand, gravel, boulders, and locally-cemented conglomerates. These layers range from 400 to 700 feet thick adjacent to the mountains to 100 to 200 feet thick in the basin floor. The surface of the uppermost

alluvium layer is a sandy-silt containing some gravel and occasional boulders (NMED, 2009).

Groundwater is the primary water supply in the area for nearly all uses (i.e., potable, industrial, commercial, and agricultural). Runoff from the adjacent San Andres Mountains primarily provides recharge to the basin, with the majority (up to 75%) migrating off-site as surface runoff. The runoff that eventually reaches the alluvial fans at the base of the mountains is a small volume, but continuing source of ground water recharge in the area (NMED, 2009).

4.4 Contaminant Distribution

Between 1964 and the late 1970s, the oxidation of wastewater containing dimethylhydrazine resulted in the unintentional formation and release to grade of NDMA (Giles et al., 2004). In addition, a number of other volatile organic compounds were utilized at the facility and released, migrating into the groundwater table (Table 4.1). The contamination resulted in a groundwater plume nearly four miles in length, 1.5 miles in width, and up to 700 feet thick (Figures 4.4-4.5). The FBR demonstration was set up to treat groundwater collected from extraction wells located within this plume.

Table 4.1 WSTF historical groundwater analyses from the mid-plume area (BLM-15).

Analyte	Result (µg/L)
Nitrosodimethylamine (NDMA)	8.1-18.7
Trichloroethylene (TCE)	2.5-3.5
CFC-21	2.3-4.7
CFC-11	206-240
Freon-113	51.2-154

Figure 4.4 NASA WSTF NDMA plume.

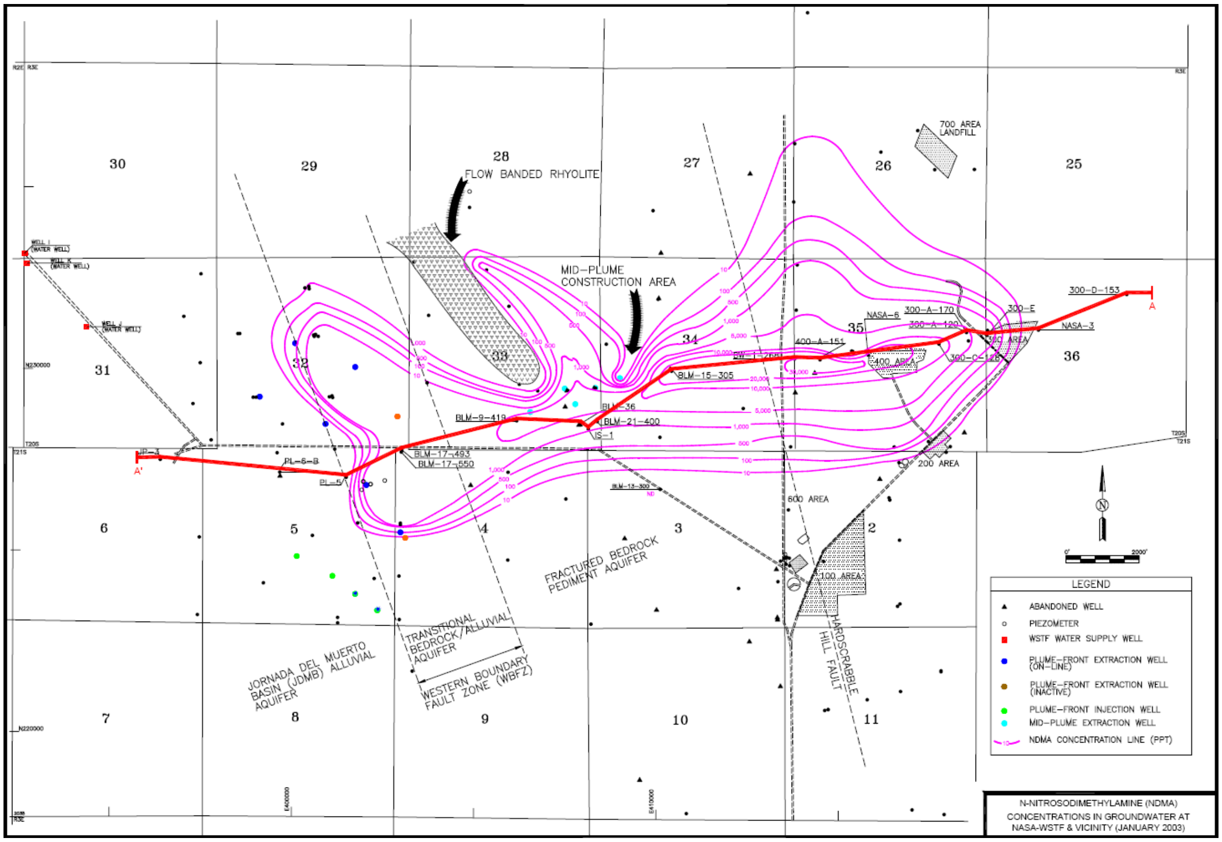
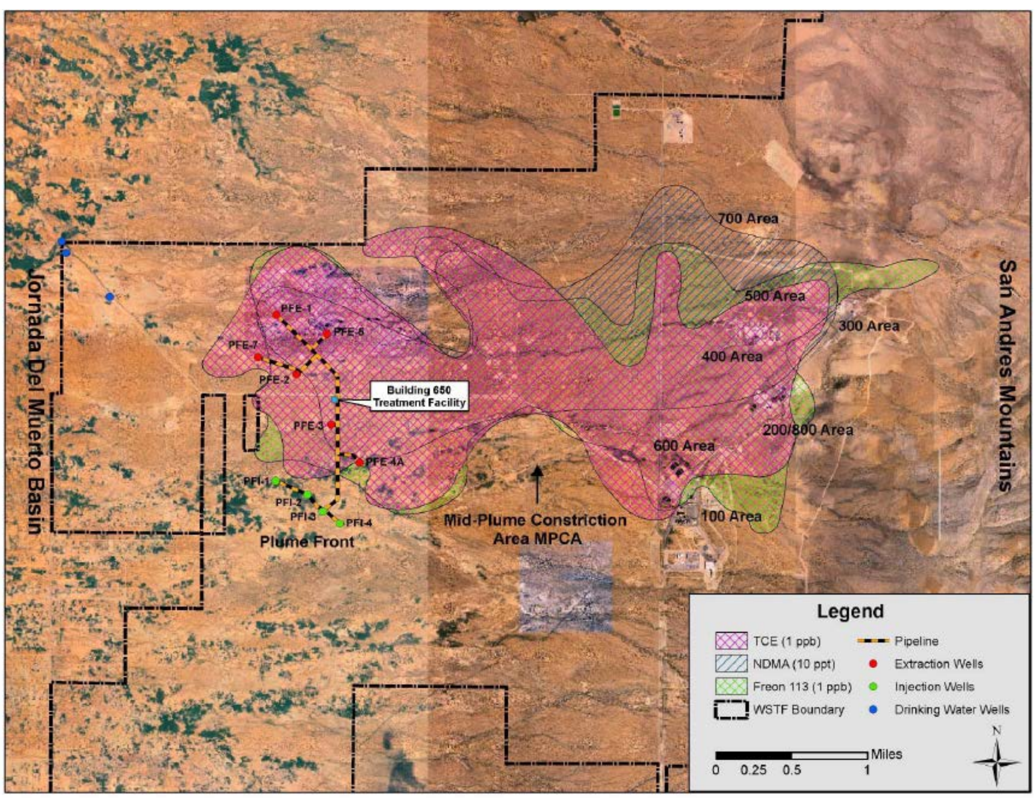


Figure 4.5 NASA WSTF NDMA, TCE, and Freon 113 plumes.



5.0 Test Design

The objective of this ESTCP project was to demonstrate biological remediation of NDMA in groundwater using an aerobic, propane-fed FBR under field conditions.

5.1 Conceptual Experimental Design

Based upon successful treatability study and bench-scale FBR results (Section 5.3; Webster et al., 2013), the pilot-scale FBR testing was conducted at the MPITS location at WSTF. The pilot-scale FBR was operated for ~ 1 year on the actual site water using coconut shell based granular activated carbon (GAC) media under various operating conditions (Figure 5.1, Table 5.1). The design of this pilot-scale FBR system utilized separate pressure vessels to add propane and oxygen to the system recycle water. All necessary engineering precautions were taken to ensure that the two gases were added safely (lower explosive limit sensors, programmed alarms, etc.). The pilot-scale system was designed to treat 1-5 gpm of water.

Figure 5.1 Conceptual set-up of pilot-scale FBR.

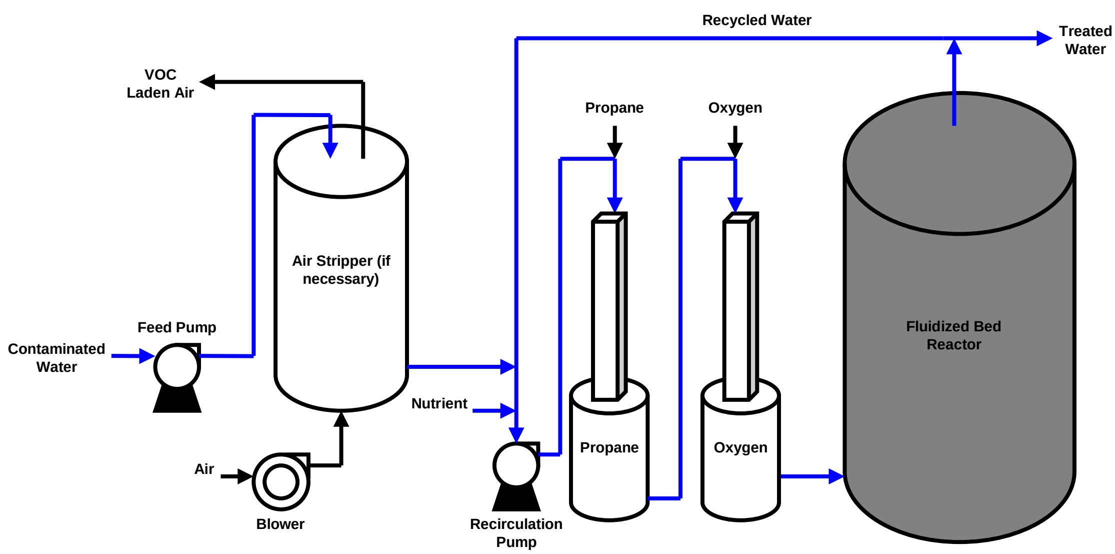


Table 5.1 Operating conditions for the pilot-scale FBR treatment.

Phase	Duration	Purpose	Changes
I	83 days (Days 0-83)	Conduct startup/Determine abiotic losses	Mechanical Shakedown/30-60 minute HRT
II	7 days (Days 83-90)	Recycle of ENV425 inoculum	Oxygen/propane addition with residual
III	90 days (Days 90-180)	Increase in ENV425 within FBR	30-60 minute HRT, Oxygen/propane addition with residual
IV	90 days (Days 180-270)	Demonstrate NDMA removal under steady-state conditions	10-30 minute HRT
V	80 days (Days 270-350)	Demonstrate NDMA removal under non-steady-state conditions	Feed shutdown/electrical shutdown/restart, nutrient interruption
VI	27 days (Days 350-377)	Demonstrate NDMA and co-contaminant removal	Bypass of air stripper to allow co-contaminants in feed.
VII	15 days (Days 377-392)	Decommissioning of Unit	Disconnect utilities/prepare for shipment

Operating parameters, such as HRT, propane and oxygen addition rates, and nutrient addition rates were adjusted based on system performance in order to optimize NDMA removal. The pilot-scale FBR system was tested with the actual site water with co-contaminants removed (via air-stripper) for the majority of the demonstration (i.e., the same water entering the UV system). At the end of the demonstration period, the air stripper was bypassed for 27 days to assess the effect of the presence of organic co-contaminants on NDMA biodegradation, simulating an air stripper failure. The unit was decommissioned after approximately 1 year of operation.

5.2 Baseline Characterization Activities

The MPITS system was designed to treat a combined influent from several different wells in the NDMA plume at WSTF. Baseline groundwater characterization was initially conducted from well BLM-15 for treatability testing (Section 5.3). The two samples of WSTF water from this well demonstrated a range for each contaminant (See Table 4.1). WSTF initiated operation of their new MPITS just months prior to the installation of the pilot-FBR system at the same location. Hence, significant water chemistry data was collected and analyzed by WSTF personnel from the MPITS influent. Representative values for NDMA and organics are provided in Table 5.2 from this initial evaluation.

Table 5.2 WSTF representative groundwater analysis from MPITS (NASA, 2013).

Analyte	Result (µg/L)
Nitrosodimethylamine (NDMA)	0.8-3.4
Trichloroethylene (TCE)	19-47
Tetrachloroethylene (PCE)	0.9-2.2
CFC-11	30-75
Freon-113	39-120

The results from Tables 4.1 and 5.2 show that the water entering the MPITS treatment plant (Table 5.2) had an overall lower concentrations of NDMA than the water originally taken from BLM-15 for treatability studies (Table 4.1). This difference likely reflects the fact that the MPITS influent was collected from more than one extraction well and blended prior to entering the plant. CFC-11 and TCE were somewhat higher in the MPITS influent than observed in BLM-15, although all of the VOCs were stripped before the groundwater entered the FBR or the UV system. In addition, the water that fed the FBR, which averaged ~ 1 μg/L of NDMA, was somewhat lower than that what entered the MPITS plant. This difference is likely attributable to the location where the samples were taken. The MPITS influent sampling occurred before a surge tank that is a combination of water from extraction wells. The UV system frequently goes into 15 minute recycle mode where effluent from the UV tower is re-circulated into the surge tank instead of being discharged into a settling basin. This occurs to allow groundwater wells to recharge and for further treatment of effluent. This recycle causes a mixing of well water with treated effluent from UV tower, which ultimately leads to a slight dilution of the concentration of NDMA in the surge tank. The feed to the FBR originated after the surge tank. Hence, this FBR influent sample is typically somewhat less than observed for the MPITS plant. All influent data reported for the FBR were taken just prior to the FBR system to represent as closely as possible the influent concentrations actually entering the reactor.

5.3 Laboratory Study Results

The treatability phase of this study entailed initial batch microcosm studies to evaluate the ability of ENV425 to mineralize the NDMA in the WSTF water, followed by extensive FBR bench-scale testing to assess reactor performance and to evaluate different operating conditions (i.e., hydraulic residence time, propane, and oxygen addition rates, etc.). The complete data from the treatability study are provided in the ESTCP treatability study report for this project (Hatzinger and Webster, 2009), and the laboratory-scale FBR results were published in Webster et al., (2013).

5.3.1 Microcosm Results

For the initial bench-scale microcosm study, ENV425 rapidly mineralized 55-60% of the NDMA in a sample of WSTF water (Figure 5.2). Based on the extent of mineralization and evidence of cell growth, the WSTF water did not appear to be inhibitory to NDMA degradation by ENV425 during growth on propane. In large-scale mesocosms prepared with WSTF groundwater and augmented with propane, oxygen, and ENV425, NDMA was degraded from ~18 μg/L to ~10 ng/L in 3 days (Figure 5.3). The killed control and live control samples did not demonstrate a similar reduction in NDMA concentration. Hence, the presence of co-contaminants or other geochemical factors within the WSTF water did not appear inhibitory to ENV425.

5.3.2 Laboratory FBR Results

Based upon successful results of the batch-scale microcosm tests, a laboratory-scale FBR was constructed at the Shaw Laboratory in Lawrenceville, New Jersey. Water chemistry characterization of the site BLM-15 well was conducted by WSTF and the analysis was supplied for the study. Based on the groundwater data, a synthetic blend of water was produced in the Shaw Laboratory to mimic the site NDMA and other chemical constituent

concentrations in groundwater. This was necessary to avoid the costs of shipping large quantities of water from the field to the laboratory (~ 55 or more gal per week). For most of the study, the WSTF synthetic groundwater was fed to the bench-scale reactor. However, during the latter phase of testing, six 55-gallon drums of contaminated site water were delivered to the Shaw laboratories to ensure the synthetic water treatment results were directly comparable to the actual site water results.

The bench-scale FBR was tested for 8 months on the synthetic site water using coconut shell based granular activated carbon (GAC, General Carbon Corporation, Paterson, NJ) media under various operating conditions (Table 5.3). The design of the bench-scale FBR system incorporated adding a Grade 2.0, 99% purity propane and zero-grade oxygen (both purchased from Airgas, Piscataway, NJ) under separate pressure vessels to the system recycle water. The bench-scale system was designed to treat up to 70 mL/min of NDMA-laden groundwater. The system design parameters included:

- Total FBR System Volume (including all piping) ~ 4.75 L
- FBR only volume ~ 3.00 L
- FBR diameter = 5 cm
- Settled bed height = 42 cm
- Hydraulically fluidized bed height = 52 cm
- Controlled hydraulic and biological expanded height = 70 cm
- Controlled hydraulic and biological expanded bed volume = 1.374 L
- Feed maximum = 70 mL/min
- Minimum HRT at maximum flow and controlled bed volume = 20 min
- Fluidization flow rate = 1.2 L/min
- Oxygen addition rate = 3-7 mL/min (4.0-9.3 mg/min at 1 atm and 22 degrees Celsius)
- Propane addition rate = 0.4-0.8 mL/min (0.6-1.2 mg/min as carbon at 1 atm and 22 degrees Celsius)

A photograph of the bench-scale FBR is provided in Figure 5.4 and a diagram of key components is provided in Figure 5.5. Initial operation of the bench-scale FBR allowed for the abiotic removal of NDMA through adsorption. Once breakthrough of the NDMA was achieved across the FBR and the steady-state operation of the system was reached, the FBR process was demonstrated to be an effective means to consistently treat 10-20 µg/L of NDMA to levels below 100 ng/L (Figure 5.6; Webster et al., 2013). When conditions were further optimized, the FBR system demonstrated treatment of the NDMA to effluent concentrations of less than 10 ng/L under specific system operating parameters:

- A 20-30 minute hydraulic retention time (HRT)
- An oxygen addition rate of 6-7 mL/min (7.9-9.2 mg/min)
- A propane addition rate of 0.6-0.8 mL/min (0.9-1.2 mg C/min)
- A diammonium phosphate addition rate of 0.58 mL/min at 88 mg/L
- A urea addition rate 0.58 mL/min at 176 mg/L

A critical factor determined during the treatability testing that affects the FBR system cost-effectiveness is the addition of the gases (oxygen/propane) to the system. Effective removal of the NDMA was demonstrated at oxygen and propane addition rates of 7.9-9.2 mg/min and 0.9-1.2 mg C/min, respectively. However, since significant residuals of oxygen and propane were observed in the FBR effluent, lower gas addition rates may be possible while still maintaining NDMA removal performance. Additional testing at the pilot-scale to further optimize this continuous addition of gases utilizing a mass flow control meter over a longer operating period allowed for the determination of the minimum required gas addition rates from which full-scale costs can be extrapolated. In addition, the performance of a pilot-scale system was anticipated to be significantly more consistent than the laboratory pilot system because (1) gas addition rates can be controlled more precisely; (2) the larger size of the FBR reduces both wall effects and channeling that occur with smaller systems; (3) fluidization is more consistent; and (4) automated biomass control is less disruptive to the FBR than manual control. Hence, the need to test a larger, more robust system in the field was deemed necessary.

In summary, ENV425 was demonstrated to biodegrade NDMA in NASA WSTF water from typical concentrations (10–20 μg/L) to less than 10 ng/L in both batch microcosms and in a laboratory pilot FBR. Based on these results, the "Go" decision to Phase 2 and Phase 3 for ER-0829 was recommended. Phase 2 involved the design and fabrication of the pilot-scale FBR for the treatment of NDMA-laden water from the WSTF site, while Phase 3 involved the operation the pilot-scale unit in the field for a one year evaluation, providing site operational experience while identifying the critical parameters for eventual full-scale design.

Figure 5.2 NDMA % mineralization by ENV425 in WSTF water.

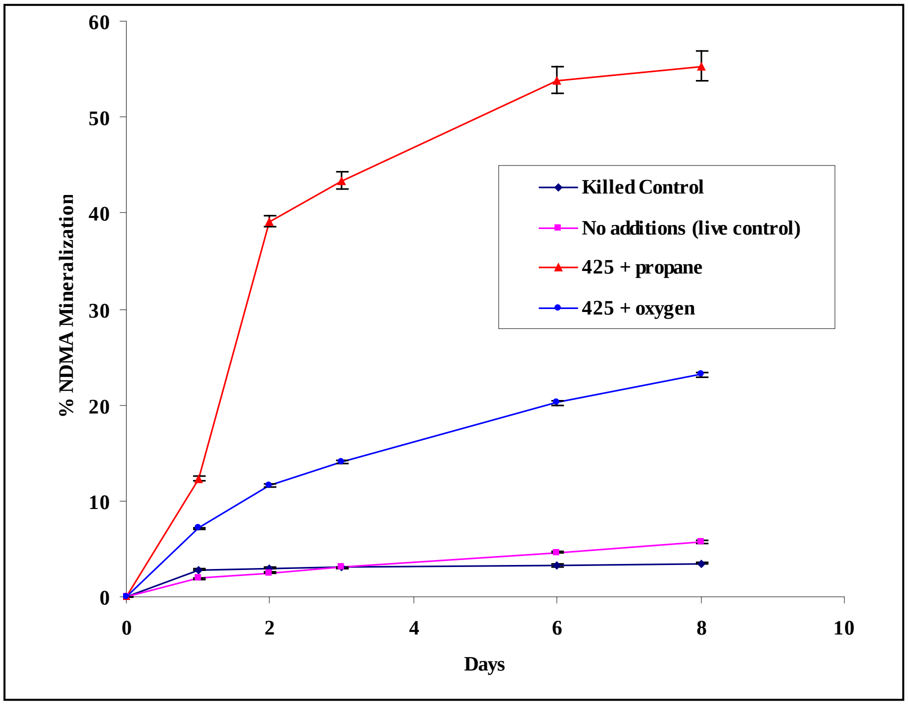


Figure 5.3 NDMA degradation by ENV425 in WSTF water.

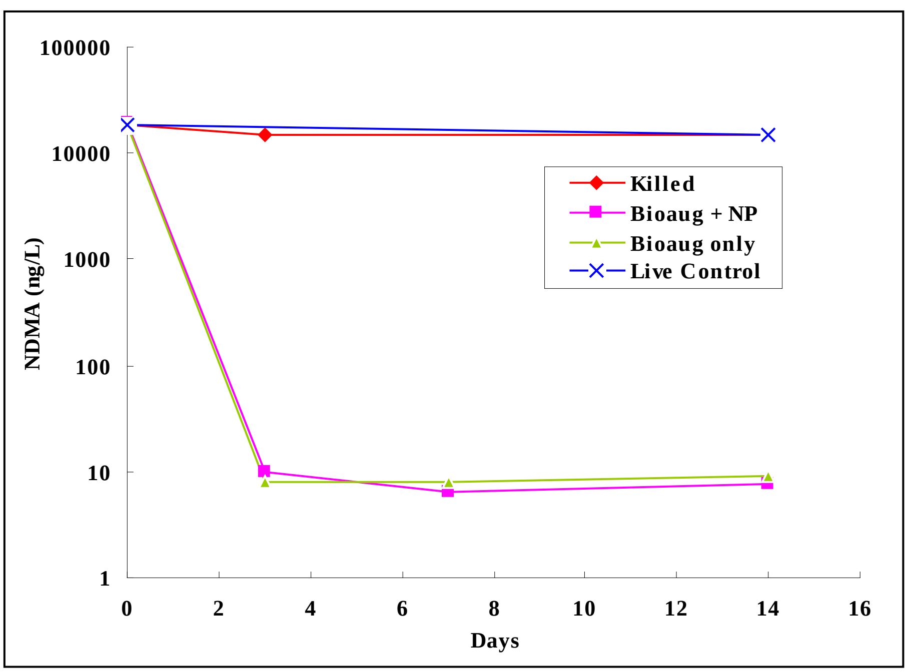


Table 5.3 Operating conditions for the bench-scale FBR treatment.

Phase	Duration	Purpose	Changes
I	54 days	Set-up/Determine abiotic losses	10-80 minute HRT
II	3 days	Recycle of ENV 425 inoculum	Oxygen/propane addition with residual
III	24 days	Increase in ENV425 within FBR	20 minute HRT, oxygen/propane addition with residual
IV	151 days	Demonstrate NDMA removal	20-30 minute HRT, add co-contaminants, feed actual site water

Figure 5.4 Photograph of the laboratory-scale FBR.

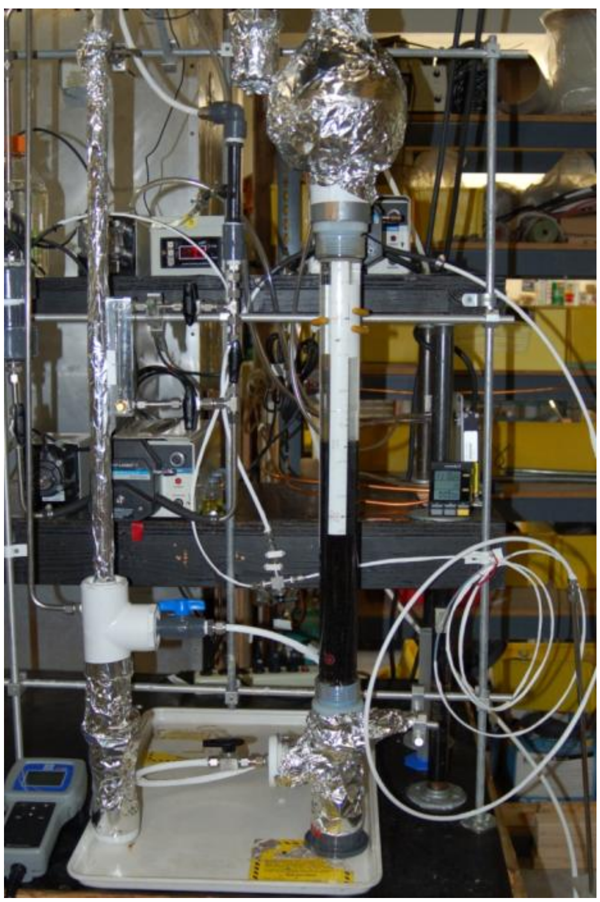
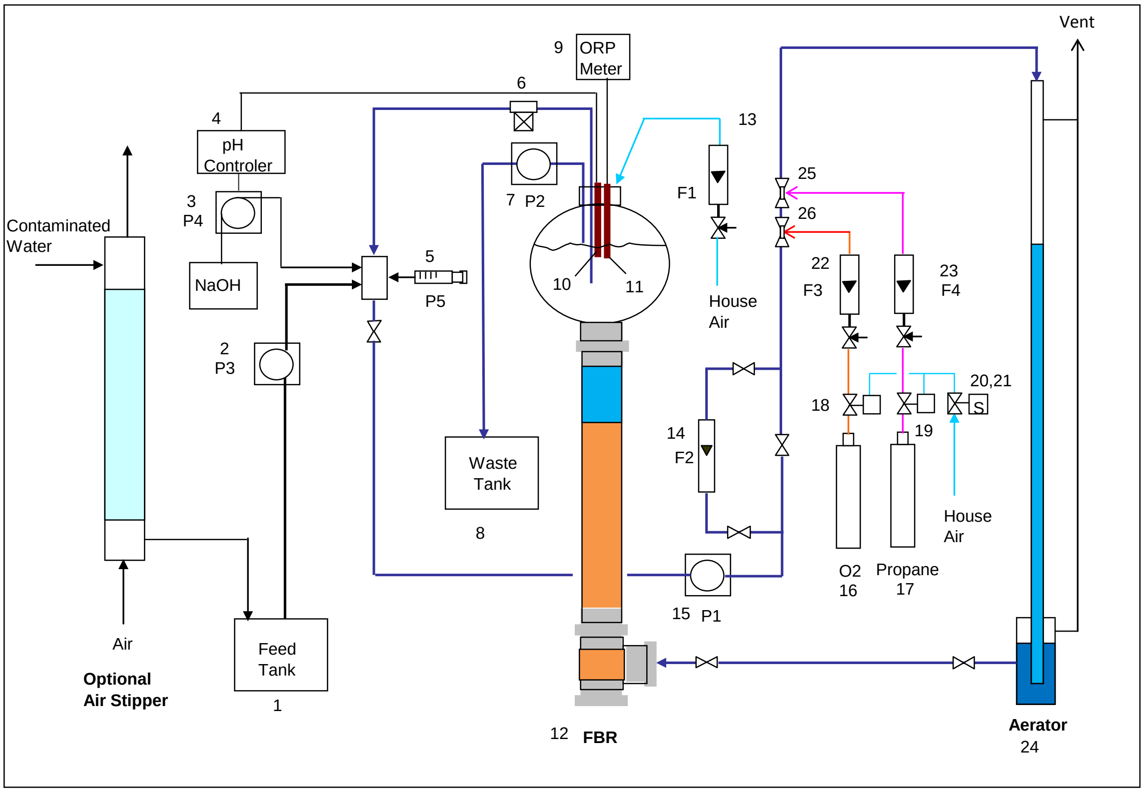
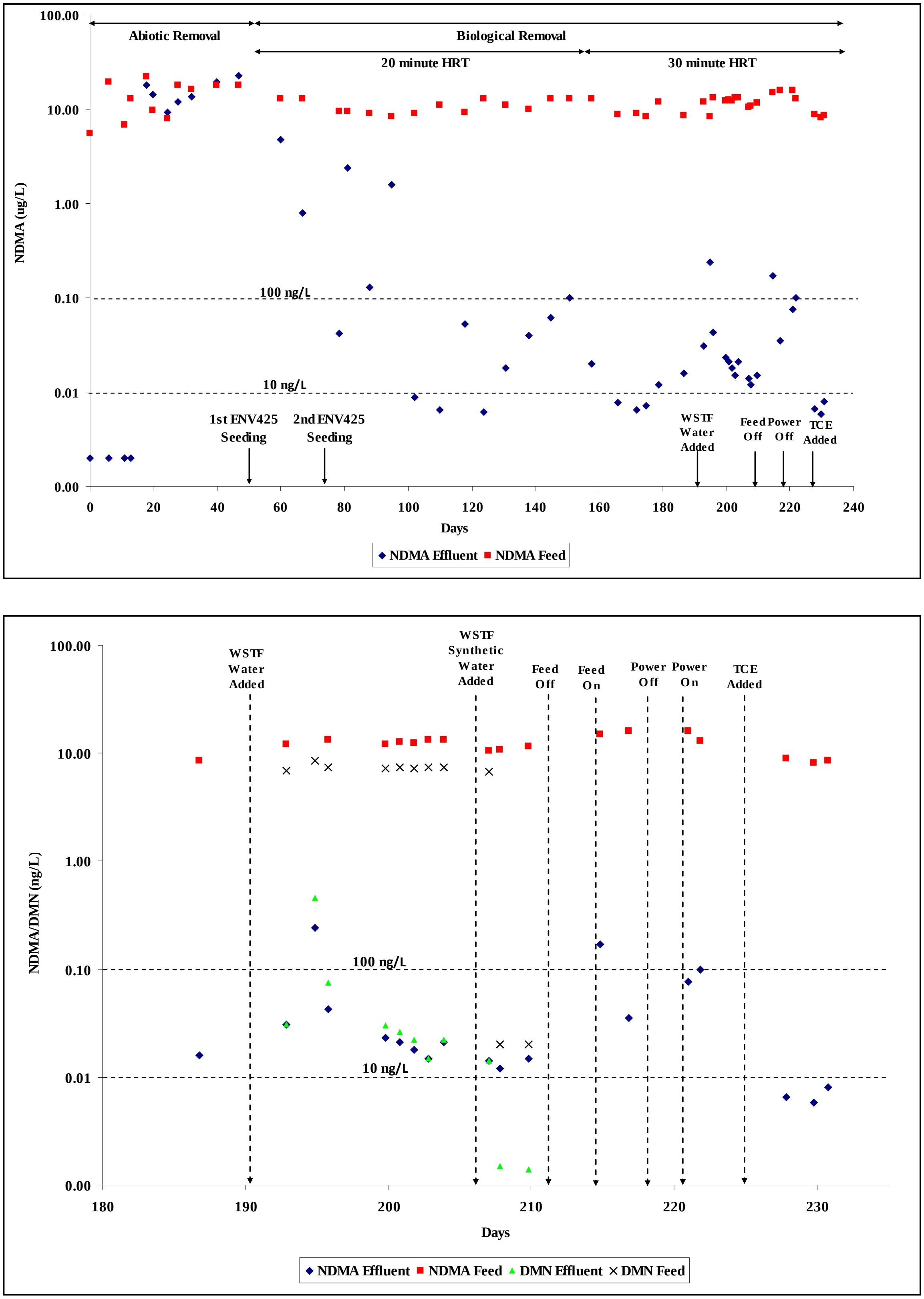


Figure 5.5 Schematic diagram of bench-scale FBR and legend of parts.



ITEM	DESCRIPTION	WHERE USED	ITEM	DESCRIPTION	WHERE USED
1	Feed Tank, 55 Gallon capacity	Feed Storage	14	Water flowmeter, 200-3000 ml/min, Acrylic, back connection 1/8" FNPT	Recirculation water
2	Diacharge pump. Driver Cole-Parmer Model 7512-50, 1-100 rpm, Pump head = 7815-12 , Tube = L/S 24 Norprene, 2.8 mL/rev	Waste discharge	15	Recirculation pump, 0 - 600 rpm driver, Easy-Load II pump head, L/S 36 norprene tubing, 4.8 mL/rev	Recirculation Pump
3	Master Flex pump. 2 rpm fixed speed driver. Standard pump head, L/S 16 Norprene Tubing (0.8 mL/rev)	pH control pump	16	Product # OXZ80, Zero grade Oxygen, 97 cu ft.	Compressed Oxgen
4	pH Controller, Model 5656-00	pH Control	17	Product # PR CPLP5, Propane, Chemically pure, LP5 cylinder, 20 LB	Compressed Propane
5	Harvard '22' Syringe Pump	Nutrient injection	18	1/4" stainless steel ball valve with pneumatic actuator for oxygen	O2 Supply
6	Nylon T-Strainer, 1/2" FNPT connection, clear bowl, 80 x 80 mesh, SS screen	Recirc. Line	19	1/4" stainless steel ball valve with pneumatic actuator for propane	Propane Supply
7	Feed pump. Driver Cole-Parmer Model 7512-50, 1-100 rpm, Pump head = 7815-12 , Tube = L/S 15 Norprene, 1.7 mL/rev	Waste discharge	20	1/4" ASCO #8314G121, 120 vac 3-way solenoid valve, brass, NEMA 4	Compressed air
8	Waste Tank, 55 Gallon Capacity	Waste Storage	21	1/4" ASCO #8314G121, 120 vac 3-way solenoid valve, brass, NEMA 4	Compressed air
9	ORP Meter	ORP Measurement	22	Direct reading flowmeter for air with valve, 65 mm, with 032-01-N tube and SS float, 0 - 50 ccpm air, Connection 1/8" FNPT	O2 flow
10	pH Probe	pH Control	23	Direct reading flowmeter for air with valve, 65 mm, with 032-01-N tube and SS float, 0 - 50 ccpm air, Connection 1/8" FNPT	Propane flow
11	ORP probe with 6-ft cable	ORP Measurement	24	Aerator assembly, effective volume = 1750 mL	Aerator
12	Reactor Assembly, 4 L working volume, Glass	FBR Vessel	25	Liquid Injector, 1/2" MT BLK GRPP, 1/4" injection port	Aerator
13	Air flow meter, 2-24 L/min, 1/4" FNPT connection in back, with valve	purging air flow	26	Liquid Injector, 1/2" MT BLK GRPP, 1/4" injection port	Aerator

Figure 5.6 Removal of NDMA over the duration of the laboratory FBR study. Days 180-230 detailed in bottom panel (modified from *Webster et al., 2013*).



5.3.3 GAC Adsorption Study

It was necessary to establish that the NDMA treatment in the FBR was predominantly biological, rather than through abiotic means such as adsorption to the carbon. In order to confirm this fact, near the end of the laboratory FBR study (Day 236), a representative sample of GAC laden with microbes was obtained from the reactor and extracted with methylene chloride to remove any remaining NDMA. To evaluate extraction efficiency, NDMA was quantitatively adsorbed to virgin GAC and that GAC also was extracted by the same technique. Based on this testing, the amount of NDMA adsorbed on the "cleaned" FBR GAC samples could be compared with the virgin GAC samples. If the treatment within the FBR is primarily biological, then the difference between the amounts of NDMA adsorbed between the two sample types should be significant.

Based on mass balance calculations, the virgin carbon adsorbed 0.61 mg of NDMA/g GAC. After extracting the NDMA from the virgin and FBR carbon and concentrating the extraction solution for NDMA analysis, the ensuing results corroborated the effectiveness of the procedure by demonstrating only small difference between the amount of NDMA adsorbed and then desorbed on the virgin carbon. The average NDMA extracted from the virgin GAC was 0.56 ± 0.1 mg of NDMA/g GAC, or 92 % of that originally adsorbed. In contrast, the quantity of NDMA removed from the FBR GAC was 0.0002 ± 0.00006 mg NDMA/g GAC. Based on the influent and effluent concentrations of NDMA during the course of the FBR study, the theoretical loading of NDMA on the GAC was 0.45 mg NDMA/g GAC, approximately three orders of magnitude higher than that detected. Such a result indicates that a minimal amount of NDMA was adsorbed on the FBR carbon during the duration of the bench-scale FBR operation. Instead, the majority of NDMA on the FBR carbon was biologically treated. Though NDMA-laden feed water to the FBR may initially be adsorbed, the primary removal mechanism is biological treatment. Additional details are provided in Webster et al., (2013).

5.4 Design and Layout of Technology Components

The pilot-scale FBR was initially delivered and partially set up at WSTF in August, 2010. However, due to significant delays with the start-up of the MPITS, the demonstration study utilizing the FBR could not be fully initiated until March, 2012.

The feed water to the pilot-scale FBR originated from two locations of the MPITS. Location 1 was after the air stripper and used for the majority of the demonstration study. This location allowed NDMA laden feed water devoid of organic co-contaminants to be introduced to the FBR. Location 2 was prior to the air stripper and used for a short duration to demonstrate the effects of NDMA and co-contaminant-laden water on the pilot-scale FBR performance (Figure 5.7). FBR effluent water was returned prior to the influent surge tank (Figure 5.8).

The piping and instrumentation diagram (P&ID) and the system layout diagram for the complete pilot-scale FBR system are provided (Figures 5.9 and 5.10). The fluidized bed reactor is 304 stainless steel, 1 ft. diameter x 11.75 ft. straight side with carbon as the fluidized media (coconut shell based activated carbon, produced from Jacobi Carbons Aquasorb, Philadelphia, PA). The FBR system is designed to accept groundwater feed at

up to 5 gpm maximum feed loading (6.4 gpm/ft^2). The MIPTS pump (PU-6WA XM185/190) provides feed water to the UV reactor (TK-6WA, XM211) and a side stream to the FBR. A portion of this water (up to 5 gpm) passes through an actuator valve (FCV-104) on the FBR skid and enters an overflow tank (T-101). Contaminated water is pumped from the overflow tank through a strainer basket (S-101) and a feed pump (P-101), is combined with the FBR recycle water, and then proceeds through an influent pump (P-102). The operator controls the feed manually through valves V-106 and V-108. A human machine interface (HMI) screen is available to program various alarm set points to shut down the feed as necessary.

Three chemical solutions are added to the combined feed/recycle water. These include: (1) 25 wt. % sodium hydroxide from Tank T-103 and an initial (2) nutrient solution (consisting of 176 mg/L urea and 88 mg/L diammonium phosphate) from Tank 104. A third tank, T-105, is available if additional micronutrients are required. The 25 wt. % sodium hydroxide solution is automatically added to the process to maintain the FBR feed at the desired pH set on the HMI. This caustic is added from pump P-105 and the rate of addition is controlled by AIT-105, the pH controller. Sodium hydroxide solution was never required to be added to system, since the pH stayed between 6 to 9 SU during the demonstration. The nutrient solution is manually set and supplied from tank T-104 to the FBR via pump P-106. The nutrient feed is adjusted based on residual phosphorus and ammonia in the effluent in order to maintain effluent levels within permitted values. Shut down of the chemical feeds occurs based on a high or low pH, feed flow, fluidization flow, or pressure condition. These alarm set points are operator adjustable.

The combined feed/recycled water is pumped (via P-102) though a downflow bubble contactor (T-107) where oxygen is added via oxygen cylinders (T-101 and T-102). The water then passes through an educator where propane is added from two propane cylinders (T-130 and T-131).

Three different methods of propane and oxygen control addition are implemented into the pilot-scale design. These include adding proportionality constants for both propane and oxygen delivery in conjunction with feed flow rate (FIT-101), basing propane and oxygen addition on effluent oxygen concentration as measured at the top of the FBR via oxygen probe (AE-103) in conjunction with feed flow rate (FIT-101), or providing manual control of gas delivery though syringe valves.

Figure 5.7 NASA MPITS schematic with FBR groundwater feed points indicated.

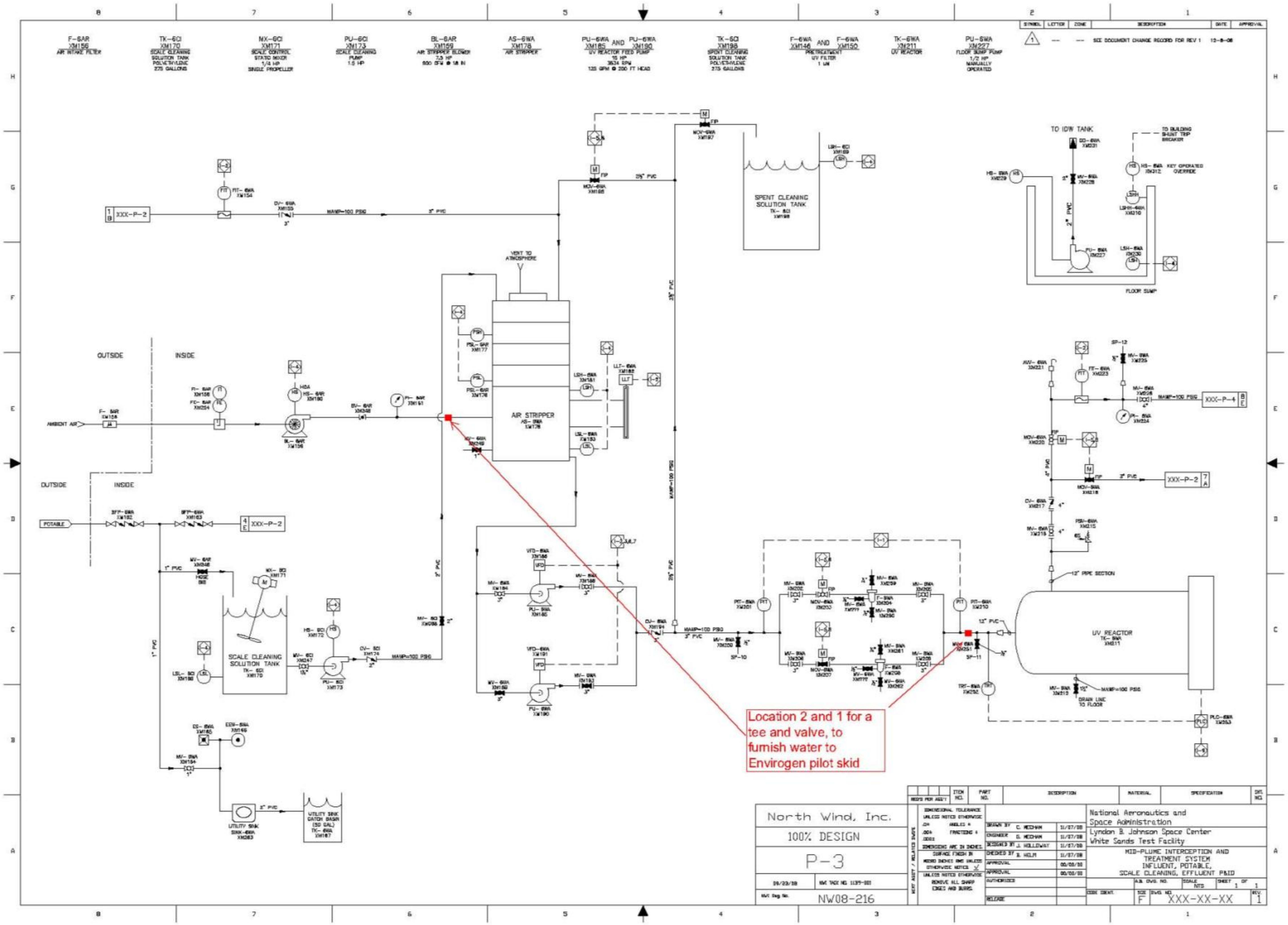


Figure 5.8 NASA MPITS schematic with FBR groundwater effluent discharge point indicated.

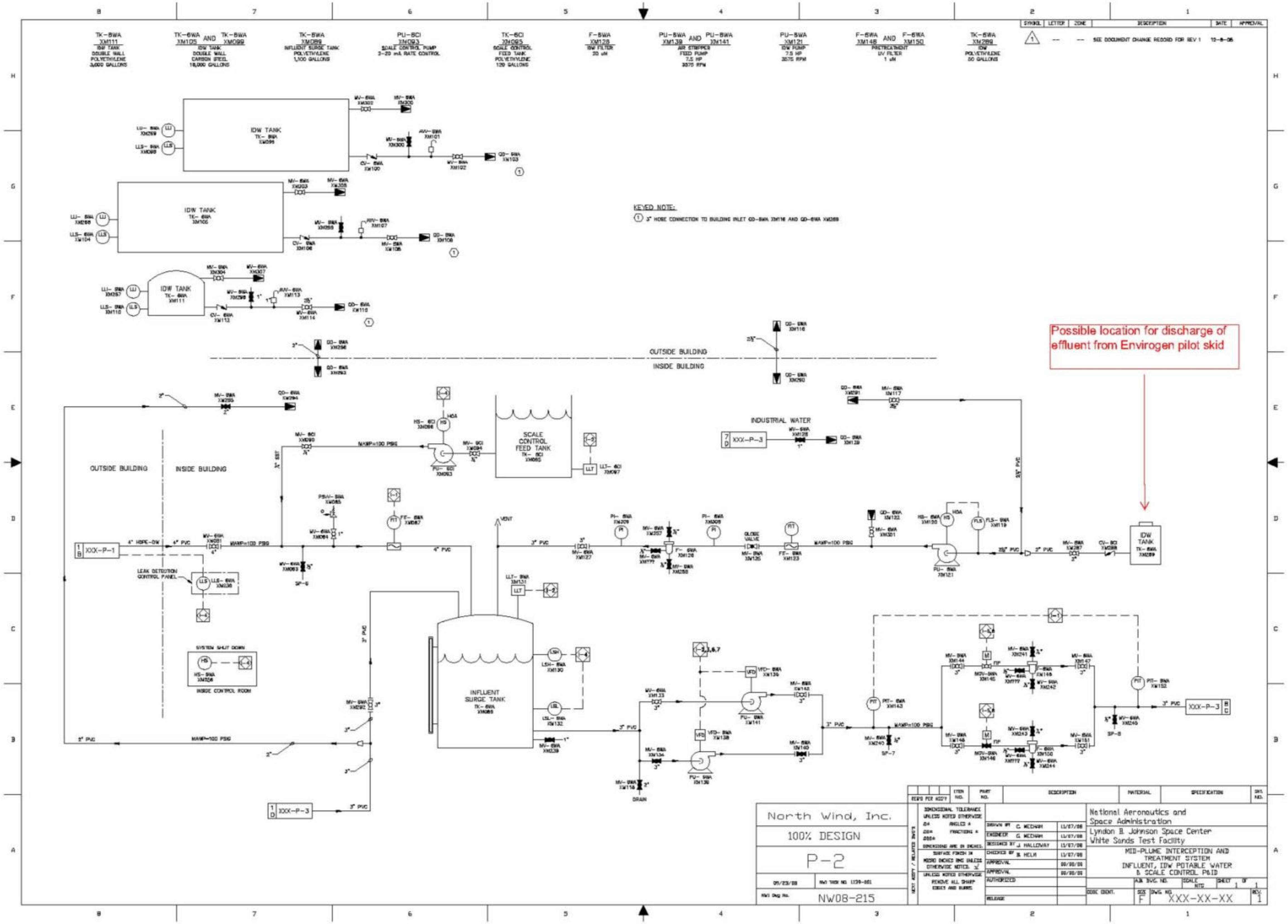


Figure 5.9 FBR piping & instrumentation diagram.

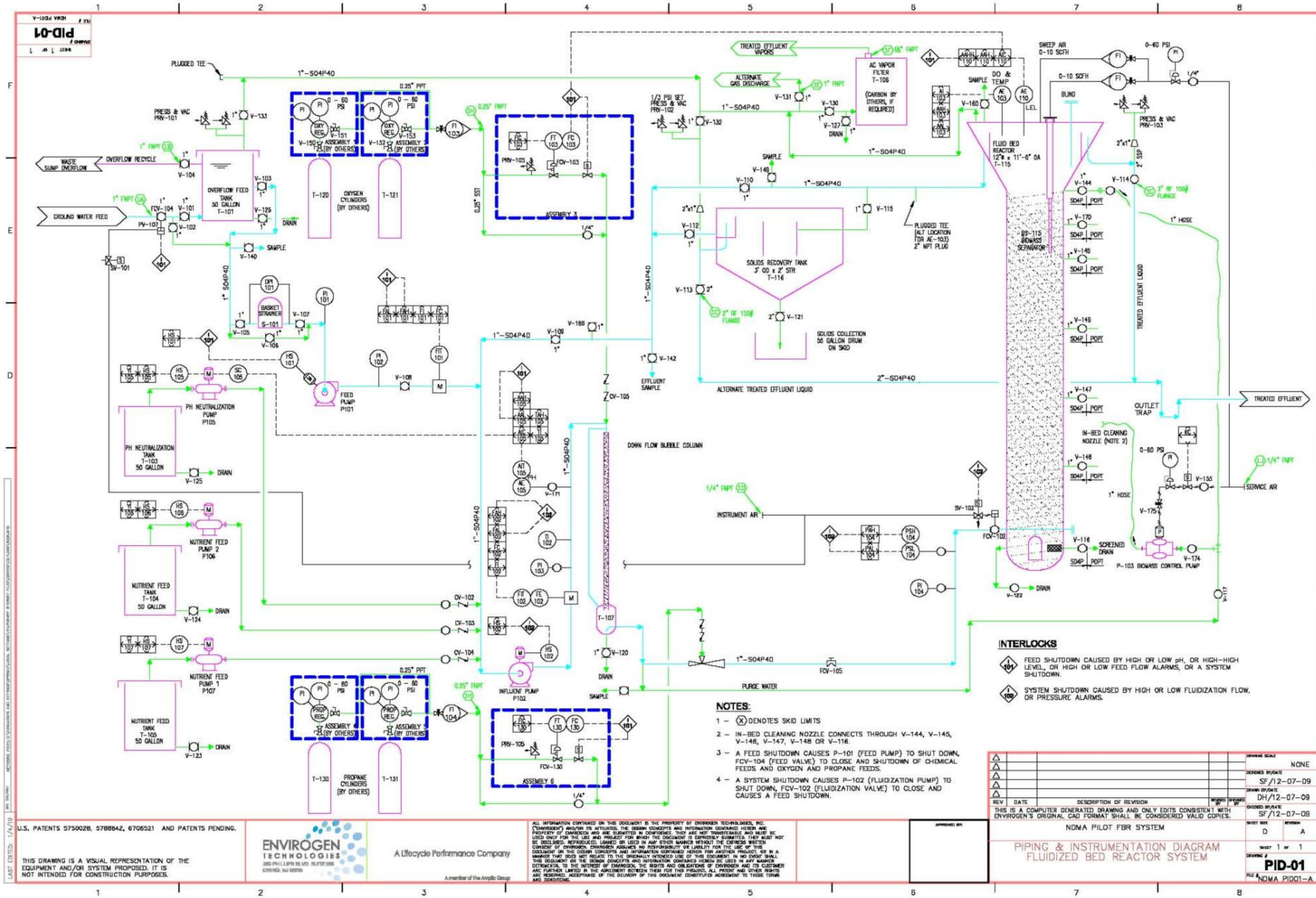
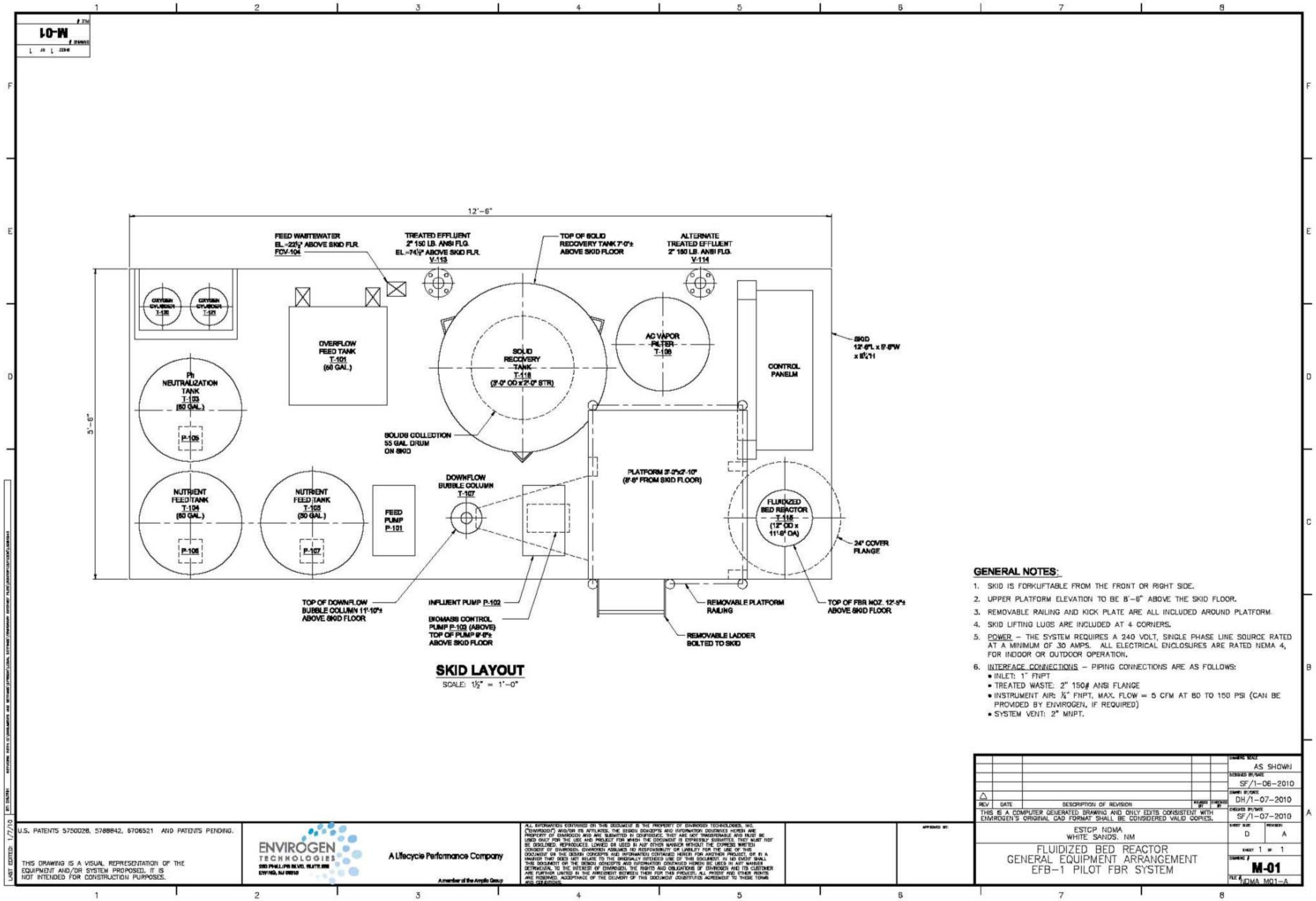


Figure 5.10 FBR layout diagram.



The combined feed/recycled water continues through an air actuated valve (FCV-102) into the base of the FBR vessel. At the base of the vessel, an integral fluidization distribution system exists to enhance uniform flow distribution upward through the FBR. This pumped water hydraulically fluidizes the carbon. A submerged dissolved oxygen & temperature sensor (AE-103) and an air exposed lower explosive limit level indicator (AE-110) are positioned at the top of the FBR to provide control of oxygen and propane to the system and prevent a hazardous air environment from developing, respectively. Sweep air is continuously provided to ensure the lower explosive limit for the propane in the headspace of the FBR is not reached. The FBR effluent water exits the vessel via gravity over an overflow weir located at the top of the reactor to the solids recovery tank (T-116). Settled solids can be removed from this tank via valve V-121. Water flows over a second weir at the back of the solids recovery tank where a portion returns as recycled water to P-102 and the balance, equaling the volume of feed water, exits as treated effluent. Treated effluent water is returned to the influent of the MPITS at the IDW Tank (TK-6WA).

Within the FBR vessel, microorganisms metabolize the propane and utilize the oxygen as an electron acceptor. The NDMA is converted cometabolically via a propane monooxgenase enzyme through a mixed denitration/demethylation pathway to low levels of innocuous products including, methylamine nitrite, nitrate, methanol, and carbon dioxide (Fournier et al., 2009; Sharp et al., 2010). As the propane is oxidized, the microbes grow and form a film on the fluidized carbon media. As the specific density of the individual carbon particles decreases, the bed fluidizes upward. At an expansion point of 1.6X the settled bed height, the media must be cleaned to prevent the carbon/biomass from exiting the system. A biomass separation system (BS-110), which uses air to physically agitate the media until the biomass is removed from the carbon particles, is used to remove biomass from carbon particles. The air for this system is provided through service air. The biomass separator may be operated on a continuous or intermittent basis, as dictated by the system operating conditions. Normally, it will be operated continuously. The separator lifts media from the top of the fluidized media bed using an air lift tube. Media with attached biomass and water is directed through the lift tubes into the mixing chamber located at the water surface. Both lifting and mixing are controlled by airflow to the biomass separator. The media and biomass are separated in the mixing chamber. The lighter biomass exits with the effluent through the overflow weir to the solids recovery tank where it settles out and the media falls back to the media bed. The following parameters are operator-adjustable:

- Airflow rate at 0 to 50 standard cubic feet per hour (SCFH). The airflow will determine the media lift rate and the degree of mixing imparted. A normal setting is 15 SCFH. To control bed height more effectively, the air lift flow will be increased while closely monitoring the effluent biomass.

- Separator elevation is adjustable using the nuts and threaded rod which hold the biomass separator in place. Raising the pipe in the separator will reduce the biomass overflow flow rate and increases the retention time of media particles in the separator, thus increasing the mixing intensity while decreasing flow.

If the bed height exceeds the 1.6X the settled bed elevation in the reactor, the biomass separation device requires inspection and if mechanical issues are observed, the airflow increased and/or the elevation adjusted.

5.5 Field Testing

Several critical system and treatment operations were evaluated during the one-year demonstration period. A number of experiments were conducted to test the robustness of the FBR technology while continuing to produce water with an NDMA concentration less than 10 ng/L. These experimental design components are discussed in detail in the following sections. All data was compiled and reviewed by the principal investigators as it became available. Weekly reports were generated by the system operator and provided to the principal investigators for review. Teleconferences were held among the principal investigators and staff to evaluate data and system performance and to discuss modifications. System modifications, including alterations in flow-rates, propane and oxygen dosage, nutrient addition, etc. were made during the demonstration. All input from WSTF staff was addressed by the Project Manager and changes were implemented as necessary.

The basic operational phases of this demonstration are presented in Table 5.1 and a schedule of these phases and other operational conditions is provided in a Gantt chart in Table 5.4

Table 5.4 Gantt chart of NDMA pilot system schedule.

NDMA FBR PILOT-SCALE SCHEDULE

TASK #	TASKS	START DATE	FINISH DATE	Elapsed Days
3	Pilot-Scale FBR Experiments	3/8/12	4/4/13	392
3.1	Phase I Start-Up/Abiotic Removal	3/8/12	5/30/12	45
3.2	Phase II Recycle Mode	5/30/12	6/6/12	15
3.2.1	ENV425 Addition and Growth	5/30/12	6/6/12	15
3.3	Phase III System Optimization	6/6/12	9/4/12	90
3.3.1	60 minute HRT	6/6/12	6/20/12	15
3.3.2	40 minute HRT	6/20/12	8/20/12	60
3.3.3	30 minute HRT	8/20/12	9/4/12	15
3.4	Phase IV Steady-State Operation	9/4/12	11/23/12	80
3.4.1	30 min. HRT	9/4/12	9/28/12	24
3.4.2	20 min. HRT	9/28/12	11/2/12	35
3.4.3	10 min. HRT	11/2/12	12/3/12	31
3.5	Phase V Challenge Experiments	12/3/12	2/21/13	80
3.5.1	Shutdown of Nutrients/Propane	12/3/12	12/12/12	9
3.5.2	Nutrients/Propane Restart	12/12/12	12/20/12	8
3.5.3	Feed Shutdown	12/20/12	1/17/13	28
3.5.4	Feed Restart (at 10 min HRT)	1/17/13	2/21/13	35
3.6	Phase VI Co-contaminant Addition	2/21/13	3/20/13	27
3.6.1	Bypass of Air Stripper	2/21/13	3/20/13	27
3.7	Phase VII Demobilization	3/20/13	4/4/13	15
3.7.1	System breakdown	3/20/13	3/29/13	9
3.7.2	Shipping of Reactor	3/29/13	4/4/13	6

Year	2012								2012								2012							
Month	Mar	Mar	Mar	Mar	Apr	Apr	Apr	Apr	Apr	May	May	May	May	Jun	Jun	Jun	Jun	Jul	Jul	Jul	Jul	Jul	Aug	Aug
Week #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Elapsed Days	3/5	3/12	3/19	3/26	4/2	4/9	4/16	4/23	4/30	5/7	5/14	5/21	5/28	6/4	6/11	6/18	6/25	7/2	7/9	7/16	7/23	7/30	8/6	8/13

Year	2012								2012								2012							
Month	Aug	Aug	Sep	Sep	Sep	Sep	Oct	Oct	Oct	Oct	Oct	Nov	Nov	Nov	Nov	Dec	Dec	Dec	Dec	Dec	Jan	Jan	Jan	Jan
Week #	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
Elapsed Days	8/20	8/27	9/3	9/10	9/17	9/24	10/1	10/8	10/15	10/22	10/29	11/5	11/12	11/19	11/26	12/3	12/10	12/17	12/24	12/31	1/7	1/14	1/21	1/28

NDMA FBR PILOT-SCALE SCHEDULE

TASK #	TASKS	START DATE	FINISH DATE	Elapsed Days
3	Pilot-Scale FBR Experiments	3/8/12	4/4/13	392
3.1	Phase I Start-Up/Abiotic Removal	3/8/12	5/30/12	45
3.2	Phase II Recycle Mode	5/30/12	6/6/12	15
3.2.1	ENV425 Addition and Growth	5/30/12	6/6/12	15
3.3	Phase III System Optimization	6/6/12	9/4/12	90
3.3.1	60 minute HRT	6/6/12	6/20/12	15
3.3.2	40 minute HRT	6/20/12	8/20/12	60
3.3.3	30 minute HRT	8/20/12	9/4/12	15
3.4	Phase IV Steady-State Operation	9/4/12	11/23/12	80
3.4.1	30 min. HRT	9/4/12	9/28/12	24
3.4.2	20 min. HRT	9/28/12	11/2/12	35
3.4.3	10 min. HRT	11/2/12	12/3/12	31
3.5	Phase V Challenge Experiments	12/3/12	2/21/13	80
3.5.1	Shutdown of Nutrients/Propane	12/3/12	12/12/12	9
3.5.2	Nutrients/Propane Restart	12/12/12	12/20/12	8
3.5.3	Feed Shutdown	12/20/12	1/17/13	28
3.5.4	Feed Restart (at 10 min HRT)	1/17/13	2/21/13	35
3.6	Phase VI Co-contaminant Addition	2/21/13	3/20/13	27
3.6.1	Bypass of Air Stripper	2/21/13	3/20/13	27
3.7	Phase VII Demobilization	3/20/13	4/4/13	15
3.7.1	System breakdown	3/20/13	3/29/13	9
3.7.2	Shipping of Reactor	3/29/13	4/4/13	6

Year	2013								2013								2013							
Month	Feb	Feb	Feb	Feb	Mar	Mar	Mar	Mar	Apr	Apr	Apr	Apr	Apr	May	May	May	May	Jun	Jun	Jun	Jun	Jul	Jul	Jul
Week #	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72
Elapsed Days	2/4	2/11	2/18	2/25	3/4	3/11	3/18	3/25	4/1	4/8	4/15	4/22	4/29	5/6	5/13	5/20	5/27	6/3	6/10	6/17	6/24	7/1	7/8	7/15

Year	2013								2013								2013							
Month	Jul	Jul	Aug	Aug	Aug	Aug	Sep	Sep	Sep	Sep	Sep	Oct	Oct	Oct	Oct	Nov	Nov	Nov	Nov	Dec	Dec	Dec	Dec	Dec
Week #	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96
Elapsed Days	7/22	7/29	8/5	8/12	8/19	8/26	9/2	9/9	9/16	9/23	9/30	10/7	10/14	10/21	10/28	11/4	11/11	11/18	11/25	12/2	12/9	12/16	12/23	12/30

5.5.1 Phase I Operation

The pilot-system arrived on site as a packaged, self-contained unit on a skid. It was unloaded and placed in the MPITS facility using a forklift (Figure 5.11). The utilities, including electrical, air, and feed, and effluent water piping, were connected by qualified site personnel. When installing the FBR system, construction waste (i.e., paper, cardboard, rubber gloves, etc.) were generated. This waste was collected and removed weekly from the site by a waste disposal company or WSTF. Additional residuals from this study, such as analytical waste or generated trash, were also removed by this company and WSTF on a weekly basis.

Figure 5.11 Photographs of installed FBR system.

Following the system installation, the shakedown of the system occurred. This shakedown required that all equipment be checked for proper operation. Using potable water, the FBR vessel was filled to normal operating levels. All of the pumps and valves were cycled for proper operation. The in-line instruments (pH, dissolved oxygen, lower explosive level detector, etc.) were calibrated per the manufacturer's recommendations. The chemical feed pumps were tested and calibrated, while the chemical feed drums were set up. Proper secondary containment was provided to address the health and safety issues and spill prevention concerns associated with the liquid amendments. Individual feed lines were run from each drum to the corresponding metering pump and from the metering pump to injection points on the FBR system. All selected piping materials were compatible with the liquid amendments.

The oxygen and propane cylinders were installed at the site. These cylinders were placed at different locations to minimize any explosion possibility. The propane cylinder was set up outside the MPITS building on the east side and using 0.25 inch stainless-steel tubing, piped to the inside of the building to the FBR skid. The oxygen cylinder(s) were installed outside on the west side of building 655 at WSTF, and using 0.25 inch stainless-steel tubing, piped to the inside of the building to the FBR skid. All system alarms and interlocks were tested to ensure proper operation (Table 5.5). After each piece of equipment on the FBR skid was verified to be working correctly, the feed water was turned on at 3 gpm and forward feed proceeded through the FBR treatment system to the gravity feed drain line. Any necessary repairs or improvements were conducted at this time prior to the carbon being added to the system.

After all systems were tested with forward feed flow, the carbon media was introduced into the FBR vessel. The upper half the FBR vessel was drained of water and the prewetted carbon media was placed manually into the vessel through the top opening. Adequate carbon media was supplied to the FBR vessel to obtain a settled bed height of approximately 175 cm (69 in), as measured with a tape measure. Once the media was added, the FBR system was placed in recycle so that the media was hydraulically fluidized 28%. A Markland 10 sludge depth meter (Toronto, Ontario Canada) was lowered from the surface of the FBR to the water/carbon interface to allow the operator to efficiently determine this fluidization of the bed. A hose was placed in the upper portion of the system to ensure that a small flow of water left the FBR and any carbon fines removed from the system. After operation of ~ 1 hr under these conditions, the recycle pump was turned off and the media was allowed to settle again. If media loss occurred, additional carbon was added through the top of the FBR vessel to return the settled bed height back to 175 cm (69 in). The recycle pump was restarted and the media fluidized once again.

Table 5.5 FBR treatment system alarms and process interlock notes.

#	Interlock Description	Resultant Action	Notes
101	High or Low pH High-High Propane Level from Detector High or Low Feed System Shutdown	Feed Shutdown P-101 shutdown-feed flow FCV-140 closes P-105/106/107 shut down – nutrient and pH control FCV-103 and 130 close-oxygen and propane	The process remains in Feed Shutdown Mode until the pH, high propane detector, high or low feed, or the system shutdown condition is corrected
102	High or low fluidization pump flow or discharge pressures	FBR System Shutdown P-101 shutdown-feed flow FCV-140 closes P-105/106/107 shut down – nutrient and pH control FCV-103 and 130 close-oxygen and propane P-102 shutdown-fluidization flow	The process remains in FBR System Shutdown Mode until the operator corrects the cause for a high or low fluidization pump flow or discharge pressure

NDMA contaminated feed water was fed continuously to the pilot scale-system until abiotic losses were determined and NDMA breakthrough observed at the effluent of the reactor. This process was estimated to take approximately 3 weeks from bench scale operation. Abiotic breakthrough did occur within 30 days, but the progression to Phase 2 was held up while safety reviews of the system operation by WSTF continued. NDMA samples were collected at the inlet and effluent of the FBR. No propane, oxygen, or ENV425 was supplied during Phase I. The Phase I loading of the carbon bed with NDMA permitted the segregation of biological degradation from carbon adsorption. Once NDMA contaminant loading was established, the system was operated in recycle mode (Phase II). Phase I was estimated to take 45 days, but it occurred for about 83 days (Tables 5.1 and 5.4).

The ETI Field Project Manager oversaw the start-up operation and provided the necessary guidance. The on-site field lab was set up, delivery schedules with the laboratory for off-site water analysis were established, and field personnel from WSTF were trained. An ETI Field Engineer was also trained on the operation of this particular system during this time. This Field Engineer was at the site three times per week over the course of the one year demonstration study and acted as a direct liaison between the WSTF and ETI. The Field Project Manager coordinated all daily activities through the Field Engineer and addressed any operational issues raised by all involved parties.

During the recycle-mode and continuous modes of operation, all system operating parameters were monitored by field personnel. Key operating parameters monitored included:

- system feed flow rate
- FBR recycle flow rate and inlet pressure
- FBR bed height
- propane/oxygen and nutrient addition rates
- FBR recycle water pH, temperature, and dissolved oxygen concentrations

Routine maintenance of the system was required to ensure that the performance was optimized throughout the study. Such routine maintenance items included:

- perform the required checklists of the key mechanical parameters
- changing out the propane and oxygen cylinders as needed
- filling the nutrient tanks as needed
- calibrating the propane/oxygen and nutrient delivery systems on a weekly basis
- calibrating the pH, DO, and Lower Explosive Limit sensors on a weekly basis
- attending to the motors, pumps, and valves to ensure continuous operation

5.5.2 Phase II

During Phase II, the FBR system was operated in recycle mode for seven days (Tables 5.1 and 5.4). Background groundwater sampling was performed from the influent of the FBR

to establish baseline conditions prior to inoculation. After all checkouts were complete, the system was ready for inoculation with NDMA-degrading strain *Rhodococcus ruber* ENV425, along with a continuous feed of nutrients, oxygen, and propane. The concentration and quantity of propane, oxygen, and nutrients added were initially based on the results from the baseline well water analysis and the stoichiometric requirements of the electron donor/acceptors. This operation in recycle mode allowed the microbes to attach to the media and begin to effectively treat the NDMA existing in the water being recycled in the FBR. Strain ENV425 was initially grown in a 25 L volume in Shaw's Lawrenceville, NJ laboratory. Upon reaching an optical density (OD_{550}) of 16.5, with an estimated cell number of 2.9 x 10^9 cells/mL, the culture was transferred to two small steel soda kegs and shipped on ice to WSTF. The culture was inoculated into the FBR on Day 84. During the recycle operation after inoculation of ENV 425, the culture was fed oxygen at a rate of 100 mg/min, propane at a rate of 15 mg/min, and nutrients were manually added as needed to keep a residual of ammonia and phosphate of 5 mg/L in the effluent. A total of 20 g of DAP and 8 g of urea were added manually to the top of the FBR column during the 7-day recycle mode.

On-site analytical tests for dissolved oxygen were conducted weekly and off-site analytical tests for propane and NDMA conducted twice a week to determine if the inoculated culture was active. The bed height also was measured to assess bed growth as a measure of biofilm formation by the inoculated culture. Based on these measures, as well as measured effluent concentrations of NDMA, it was determined that a second inoculation was not required. Effluent concentrations of NDMA were below 10 ng/L after 25 days of inoculation of the culture.

5.5.3 Phase III

During Phase III continuous operation of the system (~90 days), the feed flow was increased slowly. Initially, a 40-60 minute HRT (0.7-1.0 gpm) was implemented. This allowed for a gradual increase in biomass capable of growing on propane and treating NDMA. Oxygen, propane, and nutrient addition rates were established by adjusting pumping rates so that residuals of the chemicals were measured via instrument analysis in the effluent of the FBR. Based on the bench-scale operation, the initial loading rates for oxygen, propane, and nutrient addition at the pilot-scale were established to be 284 mL/min (373 mg/min), 32 mL/min (48 mg C/min), and 23-30 mL/min, respectively. However, these higher loadings of oxygen and propane were not sustainable as they created potential safety risks. Hence, the loadings were reduced accordingly. Based on system performance, HRTs were then adjusted until adequate NDMA removal performance was achieved. The objective of these modifications was to minimize NDMA effluent levels (ideally to <10 ng/L) and HRT. This optimization process allowed conditions to be set for a Phase IV steady-state operation.

During the 60 minute HRT, which took place on day 90 of operation, the following operation conditions were maintained:

- An HRT of 60 minutes at a 0.70 gpm feed flow
- Oxygen feed rate between 200 mg/min to 300 mg/min

- Propane feed rate between 60 mg/min to 70 mg/min
- Diammonium Phosphate (DAP) was at a concentration of 88 mg/L and a feed rate of 32 mL/min
- Urea was at a concentration of 176 mg/L and a feed rate of 33 mL/min

Nutrients were adjusted several times during Phase III to keep a constant residual of ammonia and phosphate at 0.5 mg/L or higher in the effluent based on the field test kits.

On day 112, a 40-minute HRT was implemented and the operation conditions were:

- A feed flow of 1.0 gpm
- Oxygen feed rate of 200-300 mg/min
- Propane feed rate of 40-60 mg/min
- DAP concentration of 110 mg/L at a feed rate of 25 mL/min
- Urea concentration of 352 mg/L at a feed rate of 28 mL/min

On day 165, the system was operated at a 30 minute HRT with the operation conditions:

- A feed flow of 1.45 gpm
- Oxygen feed rate of 200-260 mg/min
- Propane feed rate of 40-50 mg/min
- DAP concentration of 110 mg/L at a feed rate of 25 mL/min
- Urea concentration of 352 mg/L at a feed rate of 28 mL/min

5.5.4 Phase IV

Phase IV of the project involved operating the system at the ideal operating conditions from Phase III and assessing the robustness and reliability of the treatment process (~80 days). It was critical to demonstrate the sustained, continuous treatment of NDMA over a longer duration. During this phase, the system operated initially at steady-state at an HRT of 30 minutes for 24 days. Then, approximately each subsequent 30 days involved another step down in HRT from 30 to 20 minutes and then 20 minutes to 10 minutes. During all of these step downs in HRT, the oxygen, propane, and nutrient addition rates were modified to ensure the minimum amount of chemical addition occurred while still maximizing NDMA removal.

On day 180 in Phase IV the system continued from Phase III to be operated at a 30 minute HRT with the operation conditions as follows:

- A feed flow of 1.45 gpm
- Oxygen feed rate of 200-260 mg/min
- Propane feed rate of 40-50 mg/min
- DAP concentration of 110 mg/L at a feed rate of 25 mL/min
- Urea concentration of 352 mg/L at a feed rate of 28 mL/min

On day 204, the feed flow was increased to establish at a 20 minute HRT with the following operation conditions:

- A feed flow of 2.2 gpm
- Oxygen feed rate of 175 mg/min
- Propane feed rate of 30-40 mg/min
- DAP concentration of 110 mg/L at a feed rate of 30 mL/min
- Urea concentration of 352 mg/L at a feed rate of 31 mL/min

On day 239, the feed flow was again increased to establish a 10 minute HRT with the operation conditions:

- A feed flow of 4.3 gpm
- Oxygen feed rate of 130 mg/min
- Propane feed rate of 40-50 mg/min
- DAP concentration of 110 mg/L at a feed rate of 35 mL/min
- Urea concentration of 352 mg/L at a feed rate of 40 mL/min

A 10 minute HRT was maintained for the remainder of the field study.

5.5.4.1 Microbial Diversity Study

A study was conducted to determine if ENV425 was present in the FBR over the course of the study (or if other propanotrophs had outcompeted this strain). For this study, duplicate samples of GAC with biomass were collected from the top third of the FBR column on three separate occasions. The samples were sent on ice to Microbial Insights (Rockford, TN) for Denaturing Gradient Gel Electrophoresis (DGGE) to separate dominant organisms in the biomass, followed by identification of prevalent DGGE bands via 16S rDNA analysis. The three duplicate samples were collected on Days 112, 249, and 370 at depths of 6 ft. and 8 ft. from top of column using a long pole with a glass beaker. The pole was inserted into the bed and when the desired depth was reached, a string attached to a stopper on the top of the beaker was pulled so that GAC from the desired depth filled the beaker. Each GAC sample was then poured into a 50 mL bottle and put in cooler on ice. The samples were packed in ice packs in a small cooler and shipped to Microbial Insights, Inc. (Rockford, TN) via next day delivery.

5.5.4.2 GAC Adsorption Study

Extraction of GAC media from the FBR was conducted near the end of the field study to confirm that NDMA removal in the FBR was biological, rather than through adsorption to GAC. A representative sample of GAC within the FBR was obtained from the reactor near the end of the study (Days 357) at a depth of 6 ft from the top of the GAC bed and placed in a 1 L plastic HDPE bottle. In addition, virgin dry GAC was collected from a bag at the facility and placed in a1 L HDPE bottle. The samples were placed in a cooler on ice and shipped to Shaw's laboratory (Lawrenceville, NJ) for analysis.

The sample of virgin GAC was prepared to assess the extraction efficiency of NDMA from the carbon. For this treatment, approximately 240 mL of virgin GAC was placed into a 1-L plastic bottle and saturated with water. The water was then decanted and 1 L of a solution containing 36 mg/L of NDMA was added to the virgin GAC sample. After 5 days of incubation in the dark at room temperature (22^{o}C), the NDMA-laden virgin GAC was

removed from the spiked water and the water was analyzed for NDMA concentration. The water was decanted, and the GAC was then extracted as described in the next paragraph.

In order to extract NDMA from the GAC, two 60 mL samples of the filtered virgin GAC (~ 30 g dry wt) and two 60 mL samples of the washed GAC (hand washed in distilled deionized water to remove biomass) from the bioreactor were placed into 250 mL amber bottles. One-hundred and fifty mL of dichloromethane (DCM, HPLC grade, Fisher Scientific, Pittsburgh, PA) was then added to each of the four 250 mL extraction bottles. Each of the four bottles was then placed on an orbital shaker for 24 hrs. The four bottles were then removed from the shaker and the liquid from each bottle was decanted off through a fine mesh stainless steel screen into four individual 250 mL amber bottles. Excess water was aspirated off the top and the DCM was passed through sodium sulfate for additional dewatering. A deuterated surrogate was then added (d^6-NDMA) to estimate extraction efficiency. The DCM extractions were reduced to 1 mL volume each using a TurboVap II Concentration Work Station (Zymark Corp., Hopkinton, MA) and transferred to autosampler vials for NDMA analysis. The GAC was placed in an oven at 100^oC to dry overnight for mass determination. Based on this testing, the amount of NDMA adsorbed on the "cleaned" FBR GAC samples could be compared with the virgin GAC samples. If the treatment within the FBR is primarily biological, then the difference between the amounts of NDMA adsorbed between the two sample types should be significant, as was observed for the laboratory scale FBR (Section 5.3; Webster et al., 2013).

5.5.5 Phase V

Challenge experiments were conducted in Phase V to assess the ability of the FBR technology to rebound from feed flow interruption, system shutdowns, and propane and nutrient feed interruptions. For the feed flow interruption, the FBR system remained in recycle mode so that the media bed remained fluidized. Oxygen and propane continued to be added to maintain microbial growth. The feed shutdown mimicked a situation in which a groundwater pump failed or forward flow to the FBR was otherwise interrupted. The experimental feed shutdown was conducted for 28 days (Days 287-315). The oxygen flow rate occurred between 100 to 130 mg/min, propane at 10 to 15 mg/min, and the 14 grams of diammonium phosphate and 8 grams of urea were manually added to the FBR at the top of the column. After the shutdown period ended, the system was restarted with full forward feed flow (at a 10 minute HRT). A number of unplanned feed shutdowns also occurred, primarily due to issues with the onsite UV system. During unplanned shutdowns, no influent water was provided to the FBR system for 1-5 day periods. The system was placed in recycle mode during these periods. From such experiments, effective procedures can developed for maintaining biological activity in an FBR system during short-term shutdown scenarios. Analysis of the influent and effluent NDMA concentrations was conducted several times after the restart to establish the capabilities of the system in rebounding from a short-term shutdown.

A total system shut down experiment (i.e., with no water recirculated through the FBR) was not initially planned, but power outage to the system and a complete system shut down due to equipment failure occurred on a few occasions. Pump 102, which fluidized the FBR, failed on Day 130 and the system was shut down for approximately four days while a

new pump was acquired and installed. On Day 185, a lightning strike caused a power outage to building and led to the system being shut off for one day. Several other power outages due to lightning occurred during the 30 minute HRT demonstration phase. The system was restarted when power was available to the mid-plume plant. Other power shut downs of the system occurred over Days 347-354, primarily due to a tripped breaker caused by a malfunctioning air compressor. The system experienced a complete shut down for three days starting on Day 351 until the air compressor was repaired.

The feed of both propane and inorganic nutrients was shut off on Days 270-279 to evaluate the effects of limitation of cometabolic substrate and growth nutrients on NDMA treatment. This experiment was designed to elucidate how resilient the system was to interruptions in the supply of these necessary substrates for cell growth in the FBR.

5.5.6 Phase VI

During Phase VI, an experiment was conducted where co-contaminants were purposefully introduced to the FBR along with the NDMA for ~ 27 days (Days 350-377). The introduction of these co-contaminants occurred by allowing the feed water to the MPITS to bypass the existing air stripper and be directly introduced to the FBR system. This experiment was conducted at the 10 minute HRT. The influence of these co-contaminants on NDMA removal was examined as well as the degradation potential for the various co-contaminants. Because of the short HRT and the general recalcitrance of these compounds, it was anticipated that biological treatment of TCE and freons would be minimal. More importantly, the effect of TCE and freons at WSTF site concentrations on NDMA treatment were determined, which is important for a full-scale application.

5.5.7 Phase VII

A number of demobilization activities were associated with this study. Elements of demobilization included the following:

- Disconnection and termination of electrical power to the FBR treatment system by a certified electrician
- Removal of the carbon from the FBR vessel to storage drums
- Removal and disposal of sludge from the solids recovery tank
- Cleaning out of the FBR vessel with potable water
- Removal of piping runs between equipment
- Disconnection of all equipment from the water feed and effluent discharge lines
- Capping off of the water feed and effluent discharge lines
- Removal of chemicals from the site
- Removal of the FBR skid, associated controls, pumps, and equipment
- Placement of FBR skid on a freight truck for shipment via a forklift/crane (equipment to remain the property of ETI)

The system was operated with potable water for several hours before being powered off to ensure it was fully cleaned. All water was drained from the unit and the system was disassembled for transport.

5.6 Sampling Methods

A comprehensive and accurate performance evaluation of the pilot-scale FBR treatment system depends on obtaining a complete, representative, and consistent data set chronicling the results of the demonstration. The data must define the original and changing NDMA and co-contaminant concentrations with the amount and rates of NDMA contaminant removal. Sampling activities to support the demonstration include two primary phases: (1) start-up sampling/initial system performance sampling and (2) demonstration sampling under steady-state conditions, which includes performance optimization and long-term monitoring and sampling. The primary matrix sampled during the demonstration was the raw feed groundwater (i.e., FBR feed) and the treated FBR effluent water. The Sampling Plan presented in this section specifies the sampling location, procedures for collecting samples, the sample chain of custody procedures, the required packaging, labeling and shipping procedures, data reporting procedures, and the selection of the laboratory and analytical methods. The Sampling Plan was carried out in accordance with the Quality Assurance Project Plan described in the ESTCP Demonstration Plan (Webster et al., 2010).

The parameters, monitoring locations, sampling frequency, and the sample location for the one-year period of operation for the different phases of the pilot-scale experiments are provided (Table 5.5). The analytical methods utilized are provided in Table 5.6. Grab samples were collected from the FBR feed (V-140) and before FCV-104 and effluent streams were collected after the solids recovery tank after V-113 (see Figure 5.9). Field measurements were conducted using hand-held and in-line instruments, as well as conventional methods.

Table 5.6 Monitoring program for the fluidized bed reactor treatment system.

Parameter	Typical Measurement Location	Method	Frequency (Startup)	Frequency (At Steady-State)	Sample Location	Reason for Monitoring Parameter
Ammonia	Field	Hach Test Strip	3x per week	3x per week	FBR Effluent	Used to determine if adequate nutrients are available. Measurement greater than 1 ppm.
Dissolved Oxygen (DO)	Field	In-line Sensor Probe	Continuous (checked 5x per week)	3x per week	FBR Feed FBR Effluent	Used to determine propane dosage.
FBR Bed Height	Field	Markland Model 10 Sludge Level Detector	3x per week	3x per week	FBR Vessel	Used to determine FBR bed height.
Fluidization Flow	Field	Mass Flow Indicator	Continuous (checked 5x per week)	Continuous (checked 3x per week)	FBR Skid	Used to determine bed expansion vs. recycle flow.
Nutrient Flow	Field	Calibration Columns	3x per week	2x per week	FBR Skid	Used to determine amount of inorganic nutrients (P,N) fed to FBR.
pH - Fluidization	Field	Hand-held Sensor Probe	3x per week	1x per week	FBR Fluidization	Used to confirm in-line pH probe
pH - Fluidization	Field	System pH In-line Sensor Probe	Continuous (checked 3x per week)	Continuous (checked 3x per week)	FBR Skid	Used to determine system pH to maintain appropriate biological growth conditions
Ortho-phosphate (reactive)	Field	Hach Test Strip	3x per week	3x per week	FBR Effluent	Used to determine if adequate nutrients are available. Measurement greater than 1 ppm.
Pressure Gauges	Field	System Pressure Gauges	Daily (5x per week)	3x per week	FBR System	Used to determine normal operating line pressures.
System Feed Flow	Field	System Feed Mass Flow Indicator	Continuous (checked 5x per week)	3x per week	FBR Skid	Used to determine load on reactor.
Temperature	Field	Sensor Probe/Thermometer	Continuous (checked 5x per week)	3x per week	FBR Feed FBR Effluent	Used to monitor system temperature.
Microbial Analysis	Off-site Laboratory	DGGE	Beginning, 1x	Middle and End, 1x	Upper Portion of Fluidized Bed	To determine microbial composition in the FBR over time
NDMA	Off-site Laboratory	EPA 521.0 (QA/QC samples) EPA 607 (Modified) HRMS (SWRI)	2x per week	2x per week	FBR Feed FBR Effluent	Used to confirm FBR reactor performance.

Parameter	Typical Measurement Location	Method	Frequency (Startup)	Frequency (At Steady-State)	Sample Location	Reason for Monitoring Parameter
Nitrate-N, Nitrite-N, Sulfate, Phosphate)	Off-site Laboratory	EPA 300.0	Weekly	Bi-weekly	FBR Effluent	Used to confirm field testing and nutrient addition rates.
Propane	Off-site Laboratory	GC Analysis/Henry's Law Calculation	1x per week	2x per week	FBR Effluent	Used to confirm residual propane concentration.
Total Suspended Solids	Off-site Laboratory	EPA 160.2	1x per week	Bi-weekly	FBR Effluent	Provides potential loading characteristics on discharge basin and corroborates turbidity measurements.
VOCs	Off-site Laboratory	EPA 8260	2x per week to 1x per week One time	2x per week during bypass of air stripper	FBR Effluent	Provides co-contaminant concentrations

Table 5.7 Analytical parameters and methods conducted during the pilot-scale experiment.

Analytes	Method	Bottle Size	Bottle Type	Preservative[1]	Field/Off-Site
VOCs	8260	40 mL	Amber Glass	HCL	Off-Site Lab
Propane	Modified 415.1	40 mL	Amber glass	HCL	Off-Site Lab
Ammonia	350.2	500 mL	HDPE	H_2SO_4	Field/ Off-Site Lab
Anions (nitrate, nitrite, phosphate, sulfate)	300	500 mL	HDPE	None	Off-Site Lab
TSS	160.2				Off-Site Lab
NDMA	EPA 521 (QA/QC) EPA 607 Modified SWRI HRMS	1 L	Amber Glass	Filtration/(Sodium Thiosulfate only for method 521)	Off-Site Lab
Dissolved Oxygen	Field Meter	100 mL	HDPE	None	Field
pH/Temperature	Field Meter	100 mL	HDPE	None	Field

[1] All samples were stored at 4°C and shipped on ice.

For the on-site water quality analysis, various EPA approved HACH methods were utilized. For the off-site laboratory analysis, the selected methods represented standard EPA procedures or modifications of these procedures for the analytes of concern. Grab samples were generally collected two times per week during Phase I and Phase III and Phases IV-VI for NDMA. All other water quality analyses were conducted weekly or as the experimental operation of the FBR system required (see Table 5.4). The sampling and analytical methods performed on the feed and effluent streams included NDMA analysis by EPA Method 607 (all samples); by HRMS for samples below detection by EPA Method 607 (10 ng/L PQL); and by EPA Method 521 (QA/QC split samples), VOC analysis (EPA 8260), propane analysis via GC, total organic carbon (EPA 415.1), total suspended solids (EPA 160.2), ammonia (EPA 350.2), and orthophosphate (EPA 300.0). This sampling plan provided a thorough evaluation of the potential for an FBR to remove NDMA to required regulatory levels. Tables of analytical results are provided in Appendix B.

The low level HRMS method for NDMA by SRI utilizes a high resolution mass spectrometer (HRGC/HRMS) with sample analysis in the selective ion monitoring (SIM) mode. This method was developed originally by SRI in conjunction with WSTF for low level analysis of NDMA and

DMN. For the HRMS method, the groundwater samples were initially extracted into a mixture of dichloromethane (DCM) and ethyl ether using EPA method 3510C (http://www.epa.gov/osw/hazard/testmethods/sw846/pdfs/3510c.pdf). Using this method, a 1000 mL water sample was extracted three times, each time with a 60 mL solution of 10% ethyl ether: 90% DCM. The extracts were then combined and concentrated at a temperature 75-80^{o}C under N_2 gas to final volume of 100 μL. The extracts were then analyzed suing a Waters Micromass Autospec High Resolution Mass Spectrometer interfaced with an Agilent 6890 series gas chromatograph (GC). The mass spectrometer was used in the selected ion monitoring (SIM) mode with Masslynx/Targetlynx software to acquire and process data. The GC column was a 60 meter J&W DB1701, 0.25-μM thickness, 0.32 mm ID. The injection volume was 1 μL. A splitless injection was used at a flow rate of 1 mL/min, with an injection temperature of 180^{o}C. The initial column temperature of 45^{o}C was held for 4 minutes than ramped at a rate of 10^{o}C/minute to a final temperature of 250^{o}C. The characteristic ions for monitoring of NDMA are m/z = 75, 74, 59, 43, 42, 41.

During the operation of the pilot-FBR system, a field log was maintained to record system feed and fluidization (recycle) flow rates, temperature, pH, DO, pressure, bed height, and other pertinent operating data. This daily field log was sent to the Principal Investigators on a weekly basis for review.

On-site and offsite laboratory analyses were conducted over the course of the field study. For the on-site analysis, all samples were collected by the Field Engineer and the analytical results recorded in a logbook and copied to an Excel spreadsheet for daily review by the Project Manager. For off-site analysis, all sample bottles for the upcoming round of sampling were supplied by the off-site laboratory in an insulated cooler to arrive at least one day prior to the scheduled sampling event and contained the necessary preservatives. When sampling, the Field Engineer ensured that the bottles were completely filled, with zero head-space. Therefore, when sampling, the bottle was filled to the top resulting in a convex meniscus, and the cap was filled with sample water as well. The bottles were then capped and the samples chilled in coolers immediately after collection. Coolers were kept out of direct sunlight as much as possible. The samples were stored at $\leq$ 4°C in a cooler or refrigerator before shipment to the laboratories. Shock absorbent packing was added to the cooler to prevent breakage or damage of the sample containers during shipment. A chain-of-custody (COC) form, sealed in a plastic bag to protect it from water, was securely taped to the inside lid of the cooler. The Field Engineer performing the sampling filled out and signed the COC. Samples were shipped or delivered on the day of collection when possible. The Field Engineer made sure that any coolers destined for off-site analysis were packed with sufficient ice to maintain sample temperatures at 4°C during shipment. To ensure safe transport of the samples, the coolers were securely taped all the way around. The samplers relinquished custody of the coolers to an express carrier on the same day of collection. The samplers and off-site laboratories maintained a copy of the COC as part of the sample custody file (from time of collection to analysis). Upon receipt of each sample shipment, the coolers were inspected. Any problems were noted on the COC record and reported to the Project Manager. The goal was for all samples sent to the off-site laboratories to be analyzed within the proper hold times for the requested analyses. All off-site data analysis was reported directly to the Project Manager for evaluation and inputted into an Excel spreadsheet. Concentration data was reported in units of mg/L, μg/L, or ng/L as appropriate.

Analysis of NDMA was conducted using Southwest Research Institute (SRI). SRI is a contracted lab with NASA and conducts analysis to meet the discharge permit requirements at WSTF. For some batch samples with high NDMA concentration (e.g., adsorption studies, extractions of GAC and virgin GAC) analysis was conducted at the Shaw Biotechnology Development and Applications Laboratory (Lawrenceville, NJ) by GC/MS according to the procedure described previously in Hatzinger et al., 2011. As a means for comparison of low level NDMA data between labs, the outside lab chosen for quality assurance comparison was Weck Laboratories, Inc. located in the City of Industry, CA. Weck Laboratories (Weck) is a California Department of Public Health approved lab and is listed under the State of California Environmental Laboratory Accreditation Program (ELAP). The samples sent to Weck were analyzed by EPA Method 521.

A sampling acquisition protocol for NDMA analysis was strictly adhered to. Amber bottles were used for collection and storage of samples for NDMA analysis to inhibit any losses due to UV exposure. One-liter of effluent sample is required for NDMA ng/L analysis. Hence, the collection of this 1L sample required that grab FBR effluent samples be collected. To collect samples from the reactor effluent, a 1L brown bottle was filled with water and immediately placed on ice. Once the bottle was full, the water in the bottle was passed through a Corning filter unit (sterile, 0.22-μM pore size), then transferred to a clean amber glass bottle. Such filtration provided both preservation (to stop microbial activity) and eliminated solids so that the necessary low-level NDMA method detection limit could be achieved. The filtration protocol was developed during SERDP Project ER-1456, and losses were found to be minimal from either filtration or adsorption to filtered biomass (Hatzinger et al., 2008; Fournier et al., 2009). The filtration process was checked again during this project and losses were found to be minimal.

The Quality Assurance Project Plan described in the ESTCP Demonstration Plan (Webster et al., 2010) was followed to ensure the necessary quality control samples (i.e., field blanks, equipment blanks, etc) were collected during each sampling event. In addition, the QAPP describes at length the measures that were taken to ensure the representativeness, completeness, comparability, accuracy, and precision of the data, calibration procedures, quality control checks, and corrective action. Data quality indicators are also found in the QAPP.

5.7 Sampling Results

All on-site and off-site laboratory sample results/data collected during the study are presented in Appendix B. These results are summarized in the subsequent sections.

5.7.1 NDMA and DMN

5.7.1.1 Phase I to Phase III

During Phase I (Days 0-83), NDMA-laden water was passed through the FBR to fully load the GAC prior to inoculation with ENV425 and addition of propane and oxygen. This was conducted so that the biological treatment and adsorption removal mechanisms could be clearly delineated in the ensuing phases of the study. Prior to Day 0, the system had received intermittent flow of groundwater with NDMA but this addition was routinely interrupted. The results of the continuous abiotic loading at a 2.7-3.3 gpm flow rate demonstrated that after approximately 6 days, the influent and effluent NDMA concentrations were comparable (effluent

at 0.91 μg/L and influent at 0.92 μg/L; Figure 5.12). The system continued to be operated under this flow regime while mechanical optimization continued and the inoculum was prepared for the FBR system. Additional NDMA analyses repeatedly demonstrated that complete breakthrough of the contaminant occurred. Results for DMN were similar (Figure 5.13). Thus, throughout Phase I, influent and effluent concentrations of both NDMA and DMN were the same, suggesting that no abiotic removal of either compound was occurring.

Phase II, microbial inoculation and attachment, was conducted from Days 83-90. No NDMA or DMN data were collected during this time period, as the objective was to promote cell adsorption to the GAC media, and the system was placed in total recycle during this period with no groundwater being introduced. During Phase III (Days 90-180), the HRT was gradually decreased from 60 minutes to 30 minutes. Figure 5.14 shows the recorded influent flow rates to the FBR during the project. The oxygen and propane flow rates were 200-300 mg/min and 40-70 mg/min, respectively. These levels of oxygen and propane were varied as efforts were conducted to optimize NDMA treatment and bed growth. NDMA degradation was apparent shortly after inoculation, with effluent concentrations declining from ~1 μg/L to < 10 ng/L within 25 days after ENV425 was introduced (Figure 5.12). When the HRT was decreased from 60 minutes to 40 minutes, the effluent NDMA concentrations increased to above 20 ng/L, but then declined again to < 10 ng/L by Day 165, when the HRT was reduced further to 30 minutes, where they remained for the duration of Phase III. Much like NDMA, DMN concentrations declined to < 10 ng/L during the first 25 days after inoculation with ENV425, and then they increased marginally when the HRT was reduced from 60 minutes to 40 minutes (Figure 5.13). By the end of Phase III, DMN was consistently < 10 ng/L.

5.7.1.2 Phase IV Steady State Operation

Phase IV was conducted from days 180-270. At an HRT of 30 minutes during this period of steady-state operation (Days 180-204) the average influent NDMA was 1.13 ± 0.003 μg/L and the effluent NDMA was 3.3 ± 0.6 ng/L utilizing an oxygen and propane addition rate of 200-260 mg/min and 40-50 mg/min, respectively. DMN averaged 0.58 ± 0.09 μg/L in the influent, and the effluent was consistently < 10 ng/L (MDL). With continually effective treatment at the 30 minute HRT from days 204-239, the feed flow was increased such that a 20 minute HRT was achieved. During this phase of the study, oxygen and propane feed rates were 175 mg/min and 35 mg/min, respectively. NDMA concentrations in the influent and effluent averaged 0.72 ± 0.39 μg/L and 2.3 ± 0.8 ng/L, respectively. DMN averaged 0.38 ± 0.21 μg/L in the influent, and the effluent was consistently < 10 ng/L (MDL). On Day 239 through Day 270, the system HRT was reduced further to 10 minutes. At this HRT, NDMA effluent values began to increase somewhat. NDMA concentrations in the influent and effluent averaged 0.85 ± 0.19 μg/L and 4.6 ± 1.8 ng/L, respectively. DMN averaged 0.47 ± 0.10 μg/L in the influent, and the effluent remained < 10 ng/L (MDL). The oxygen and propane feed rates were 130 mg/min and 40-50 mg/min, respectively. The data during Phase IV clearly showed that the FBR was capable of reducing NDMA to below the WSTF regulatory limit of 4.2 ng/L at a 20 minute HRT. An effluent concentration < 10 ng/L was consistently met at the 10 minute HRT, but effluent concentrations exceeded the revised WSTF discharge limit of 4.2 ng/L after a few weeks of operation. The study also showed that concurrent NDMA and DMN removal by ENV425 is possible within the same FBR system. Degradation of DMN as well as NDMA was previously observed in our laboratory for ENV425 (Fournier et al., 2009).

5.7.1.3 Phase V Challenge Experiments

Propane and inorganic nutrients were shut off from Days 270-279 (10 minute HRT) to simulate the effects of a failure in these systems. NDMA concentrations in the effluent slightly exceeded 10 ng/L on Day 272, but values did not increase further toward the 1 μg/L influent value. The data suggest that the FBR is resilient to a shutdown of propane and/or nutrients over the short term. It is possible that the bacteria utilized dead cell mass for growth and to support NDMA degradation during this time. We previously observed significant NDMA mineralization in some environmental samples that were amended with yeast extract or lactate (Hatzinger et al., 2008). After the propane and nutrient feeds were reestablished, NDMA effluent concentrations below 10 ng/L were observed within eight hours. After seven days, the effluent NDMA concentrations were below 4.2 ng/L. The concentration of DMN increased to > 45 ng/L during the 9 day period when the propane and nutrient feed was off and remained in this vicinity through Day 287, when the system shutdown experiment was conducted.

For the unscheduled groundwater feed shutdown (Days 190-195), NDMA did not exceed 4.2 ng/L upon restart at a 30 minute HRT. Similarly, DMN remained < 10 ng/L. For the scheduled feed shutdown experiment on Days 287-315 (system was placed in total recycle with continuous feed of oxygen and propane, and batch nutrient addition), the feed was restarted after 28 days and NDMA samples were collected five days after restart. NDMA in the effluent was < 10 ng/L (influent concentration 1.46 μg/L) at the first collection point after restarting groundwater flow, with subsequent samples over the next 25 days slowly declining to below 4.2 ng/L at a 10 minute HRT. DMN was < 10 ng/L upon restart of the system from an influent concentration. Results from the nutrient and feed shutdown experiments generally indicated that the FBR could recover to treatment levels below 10 ng/L within hours to a few days after restart.

Other unplanned shutdowns occurred in addition to the planned studies, and the system generally recovered quickly. On Day 186, after the system was shut down for a day due to power outage caused by lightning, the effluent NDMA and DMN were both < 10 ng/L one day after restart. Similarly, on Day 354, after the system was shut off for about three days due to the air compressor and breaker failure, sampling occurred three days after system restart and the NDMA in the effluent was observed to be 9.7 ng/L and DMN was 5.9 ng/L. Hence, the short-term unplanned shutdowns did not hinder the reactor performance significantly.

5.7.1.4 Phase VI Co-contaminant Treatment

On Days 350-377, a limited study was conducted in which the air stripper was bypassed and water contaminated with TCE and Freon 11 in addition to NDMA was allowed to enter the FBR (Figure 5.15). A low concentration of 1,2-dichlorobenzene was also present in the water (data provided in Appendix B). Treatment of NDMA to less than 100 ng/L in the presence of site co-contaminants was the objective. During the testing at an HRT of 10 minutes, influent Freon 11, TCE, and 1,2-dichlorobenzene concentrations averaged 28 ± 3, 16 ± 1, and 16 ± 1 μg/L, respectively. Effluent Freon 11 averaged 18 ± 2 μg/L, effluent TCE averaged 0.7 ± 0.2 μg/L, and effluent 1,2-dichlorobenzene averaged 0.7 ± 0.2 μg/L during the testing. The observed declines in TCE and 1,2-dichlorobenzene may have been due to adsorption or biodegradation, or a combination of these processes. For Freon 11, adsorption is the most likely loss mechanism, as ENV425 was observed to not biodegrade this compound in batch studies. The NDMA in the

effluent increased slightly from 4 ng/L to 14 ng/L after the water with VOCs passed through the FBR (Figure 5.12). DMN remained < 5 ng/L during and after the addition of the VOCs (Figure 5.13). By Day 363, effluent NDMA concentrations were < 8 ng/L, declining to < 6 ng/L by Day 375. The data suggest that short-term contact with low concentrations of TCE and Freon 11 had no significant impact on NDMA treatment. Low TCE concentrations also were observed not to affect treatment of NDMA in the pilot FBR system (Freon 11 was not added) (Webster et al., 2013).

Figure 5.12 NDMA in the FBR influent and effluent over the duration of the study.

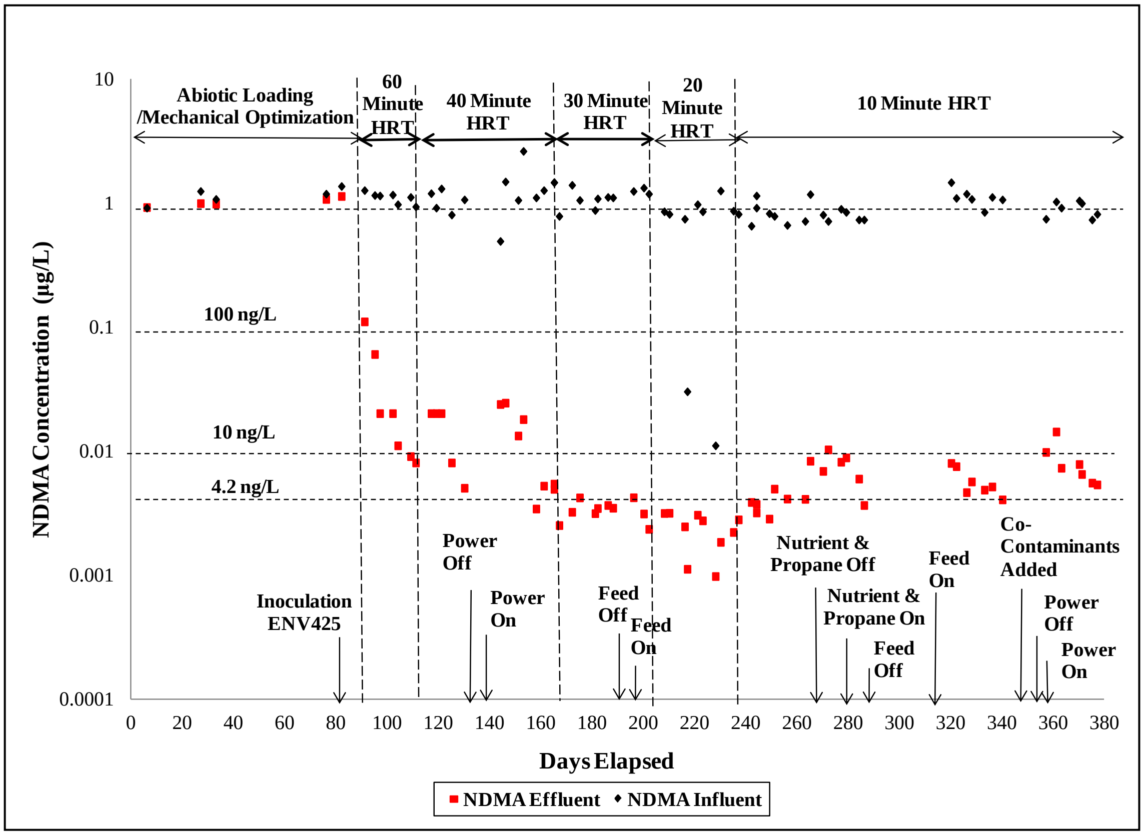


Figure 5.13 DMN in the FBR influent and effluent over the duration of the study.

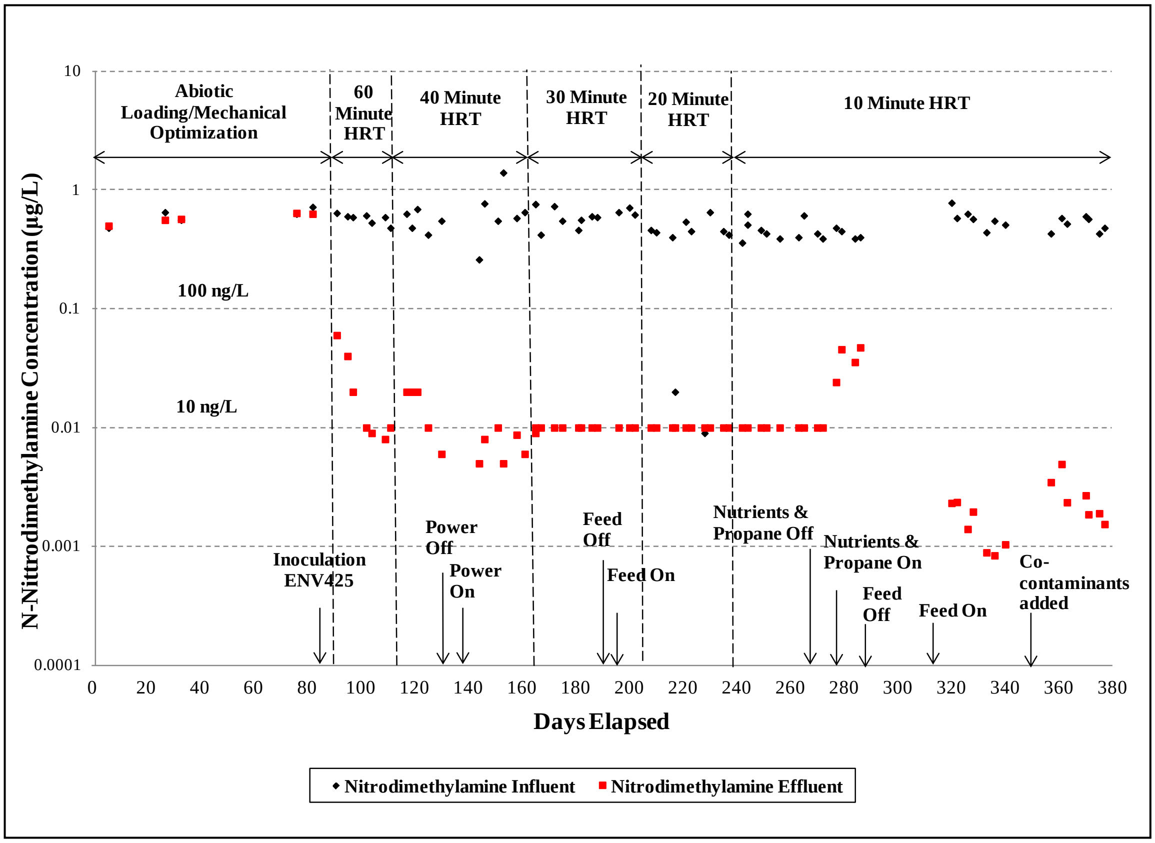


Figure 5.14 Feed flow to the FBR system.

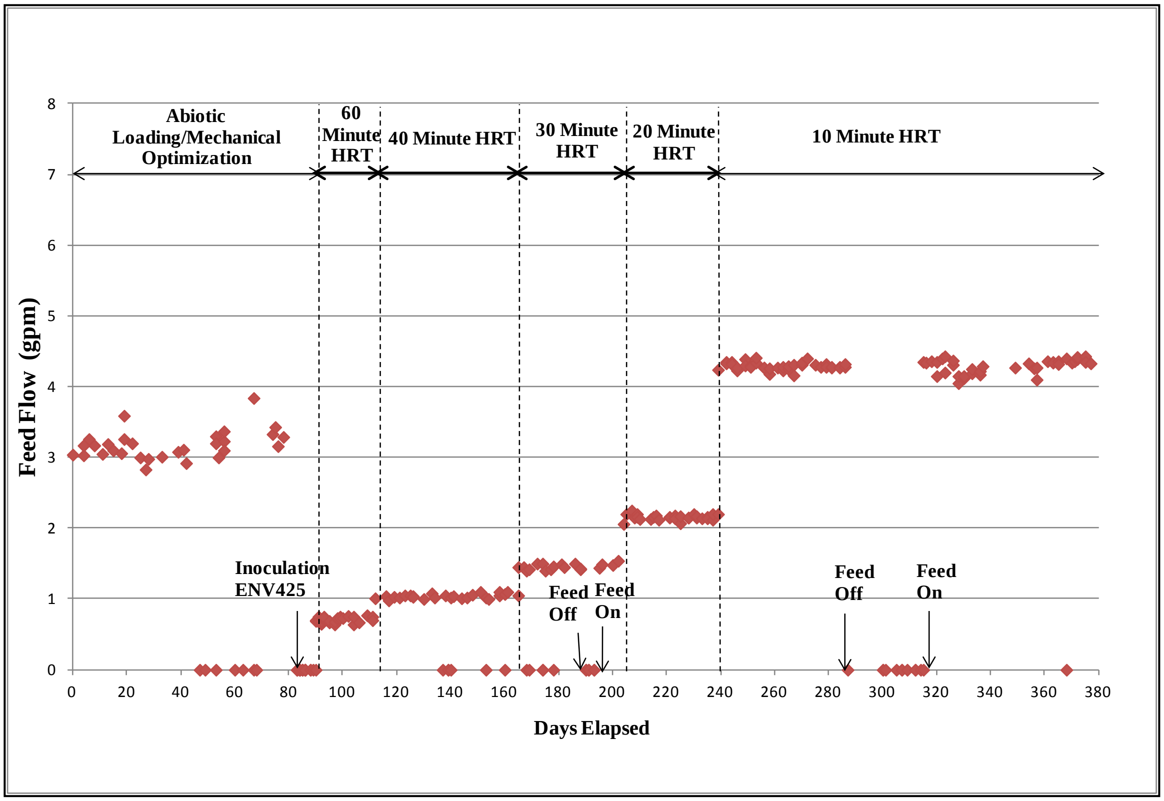
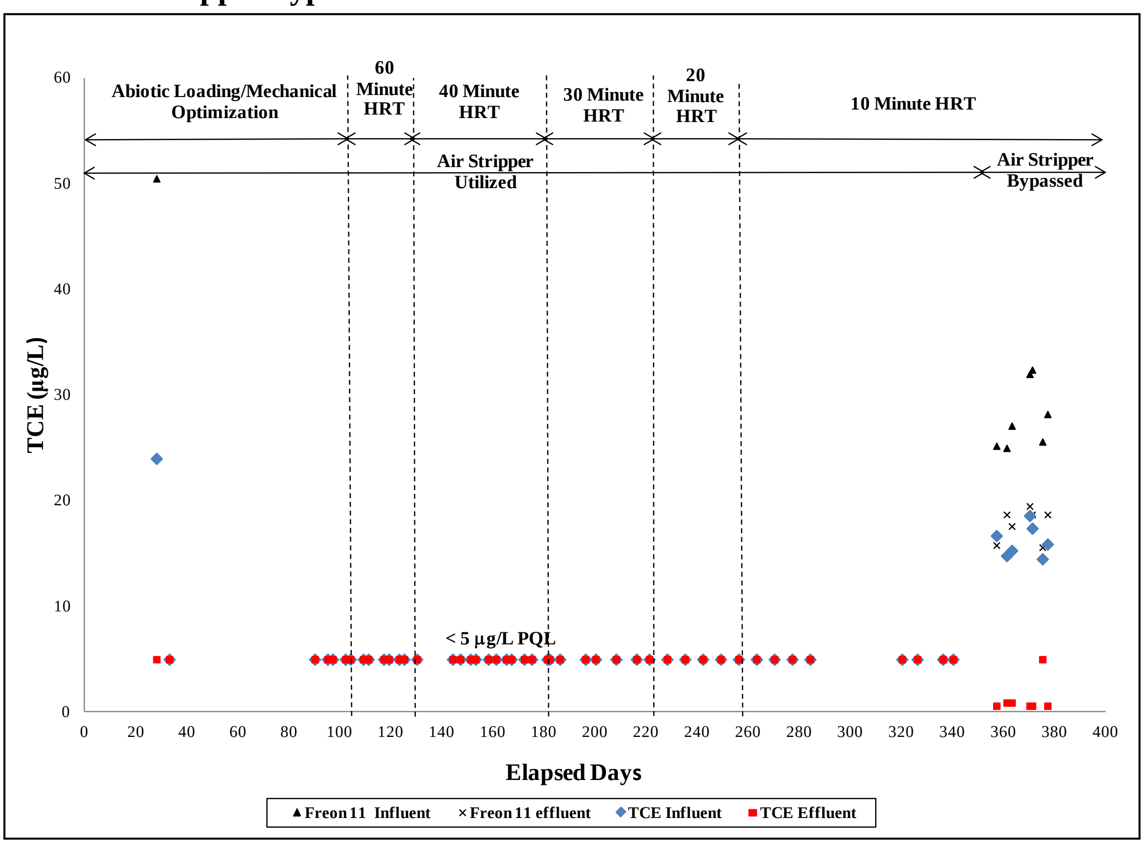


Figure 5.15 TCE and Freon 11 in the influent and effluent of the FBR system with and without the air stripper bypassed.



5.7.2 Oxygen and propane

Dissolved oxygen was measured using both an inline sensor and with a dissolved oxygen probe on grab samples throughout the several phases of operation. The inline sensor recorded concentrations of 4.2 ±1.3 mg/L in the FBR during Phase I before the DO, propane, and nutrient feed was initiated (Figure 5.16). The concentration thereafter averaged 6.4 ±1.5 mg/L, with slight declines occurring as the HRT was intentionally decreased through the course of the study. The mass of DO added to the FBR per minute (oxygen load) was reduced over the course of the study to minimize total gas addition (Figure 5.17). Based on the external probe, the concentration of DO present in the influent water to the FBR was 4.2 ± 0.4 mg/L, throughout the duration of the FBR study (Day 100 to Day 377) (Figure 5.16). These results agree with the inline probe readings prior to adding additional oxygen gas. The effluent DO concentrations were generally higher than the influent (which was expected because DO was added to the recycle line of the FBR) throughout Phase II to Phase IV until ~ Day 239, when the influent HRT was reduced from 30 minutes to 20 minutes. The influent and effluent DO were generally similar during operation at the 10 minute HRT based on the DO probe measurements. When oxygen was added to the system, the inline probe measurements were generally higher than the DO measurements taken on grab samples. This reflects differences in the sampling location, as the inline probe measured the DO at the top of the FBR after gas addition; whereas the effluent probe samples were collected downstream of the solids recovery tank but before additional DO was added. Most critically, it is clear that DO was not limiting microbial growth or NDMA degradation in the FBR through the course of the study.

The propane feed to the system was initiated on Day 83 at the beginning of Phase II, when the ENV425 culture was inoculated. Influent propane measurements were not collected during the first few weeks of operation at the 60 minute HRT, although the propane system feed was on. From the beginning of the 40 minute HRT in Phase III until the propane was shut down on Day 287 for system challenge testing in Phase V, the propane concentration in the FBR averaged 634 ± 384 μg/L (Figure 5.18). From Day 216-Day 230, no propane was detected in the FBR influent despite the flow controllers showing that it was being added to the system (Figure 5.19). The reason for this anomaly is unclear, particularly since residual propane was detected in the FBR effluent. The effluent propane concentrations from the FBR averaged 27 ± 9 μg/L from the beginning of the 40 minute HRT in Phase III until the propane was shut down on Day 287. From the shutdown period in Phase V until the end of the study, the propane was reduced, such that the influent averaged 175 ± 90 μg/L. The effluent propane during this time averaged 5 ± 3 μg/L. The data show that the FBR system generally operated with a slight excess of propane, and that propane concentrations well below 1 mg/L were effective for treating NDMA to < 4.2 ng/L at the 20 minute HRT.

Figure 5.16 Dissolved oxygen in the influent and effluent of the FBR system over the duration of the study.

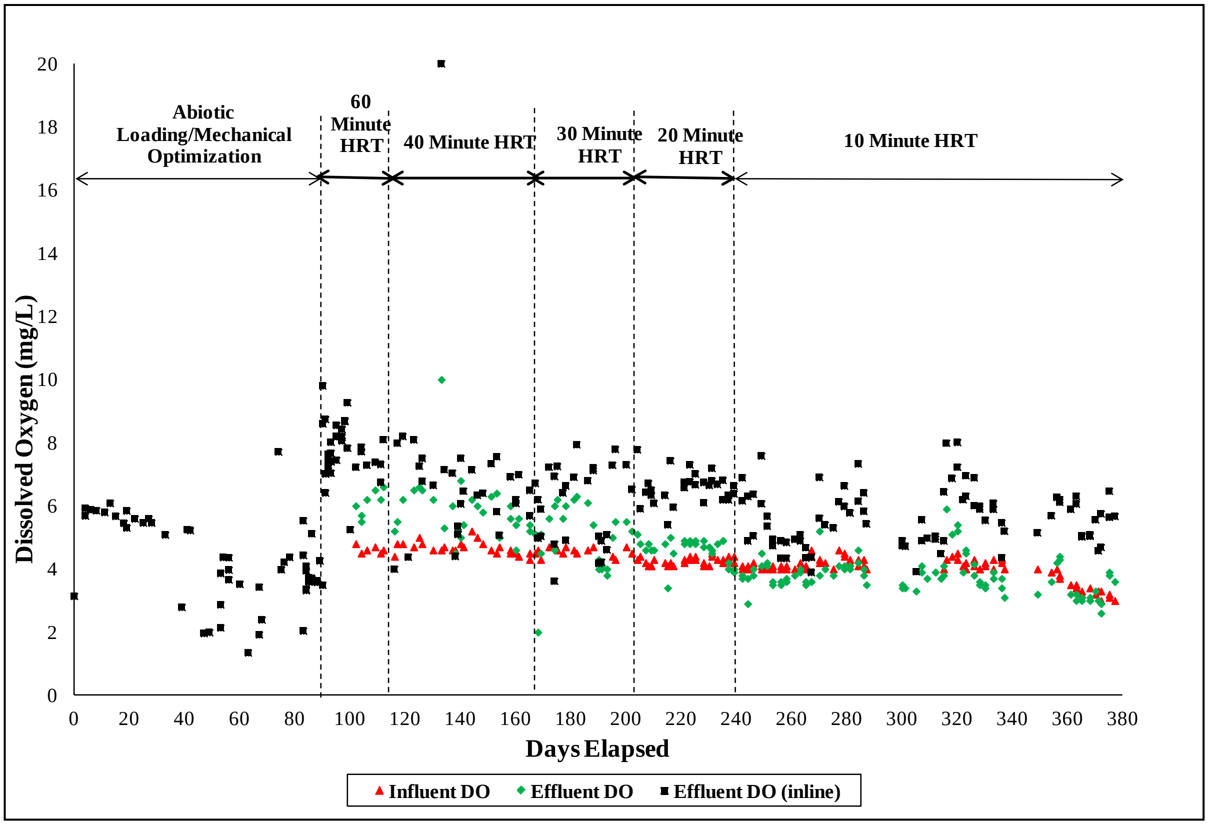


Figure 5.17 Oxygen load (mg/min) to the FBR system over the duration of the study.

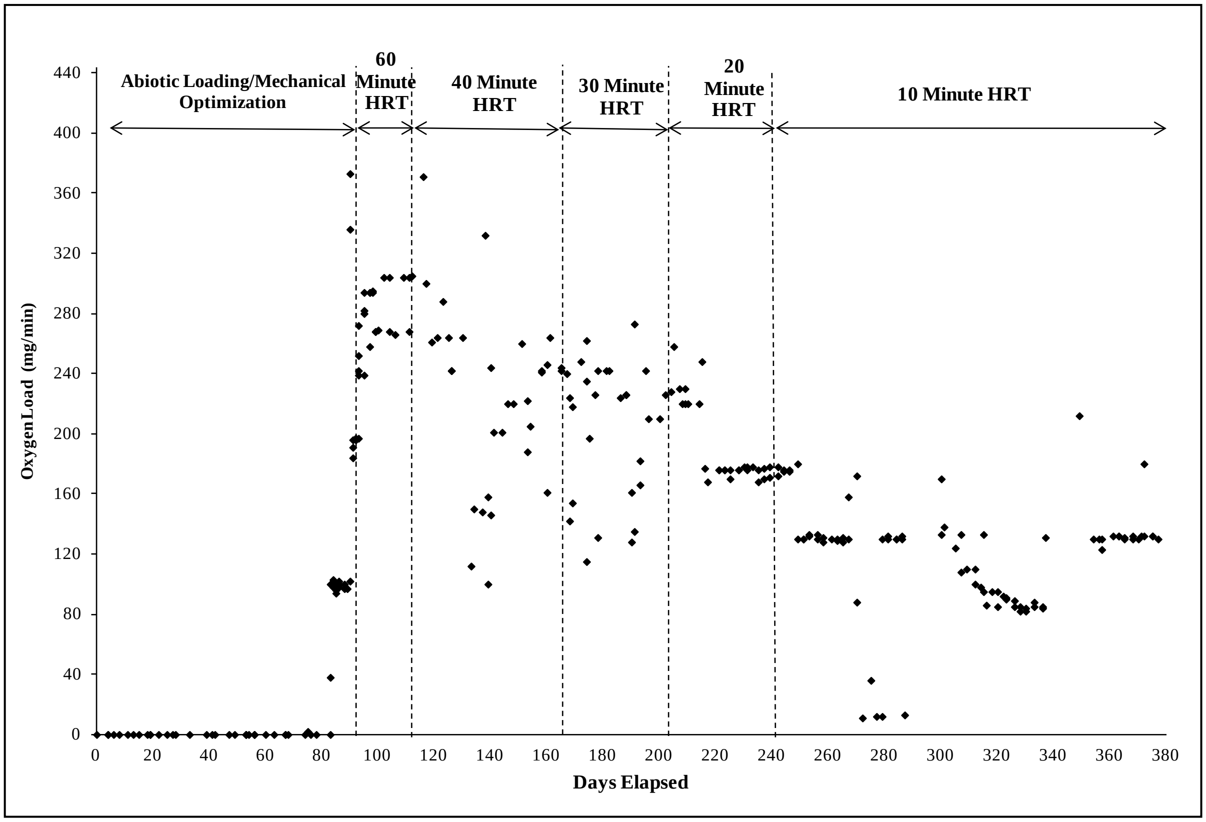


Figure 5.18 Dissolved propane in the influent and effluent of the FBR system over the duration of the study.

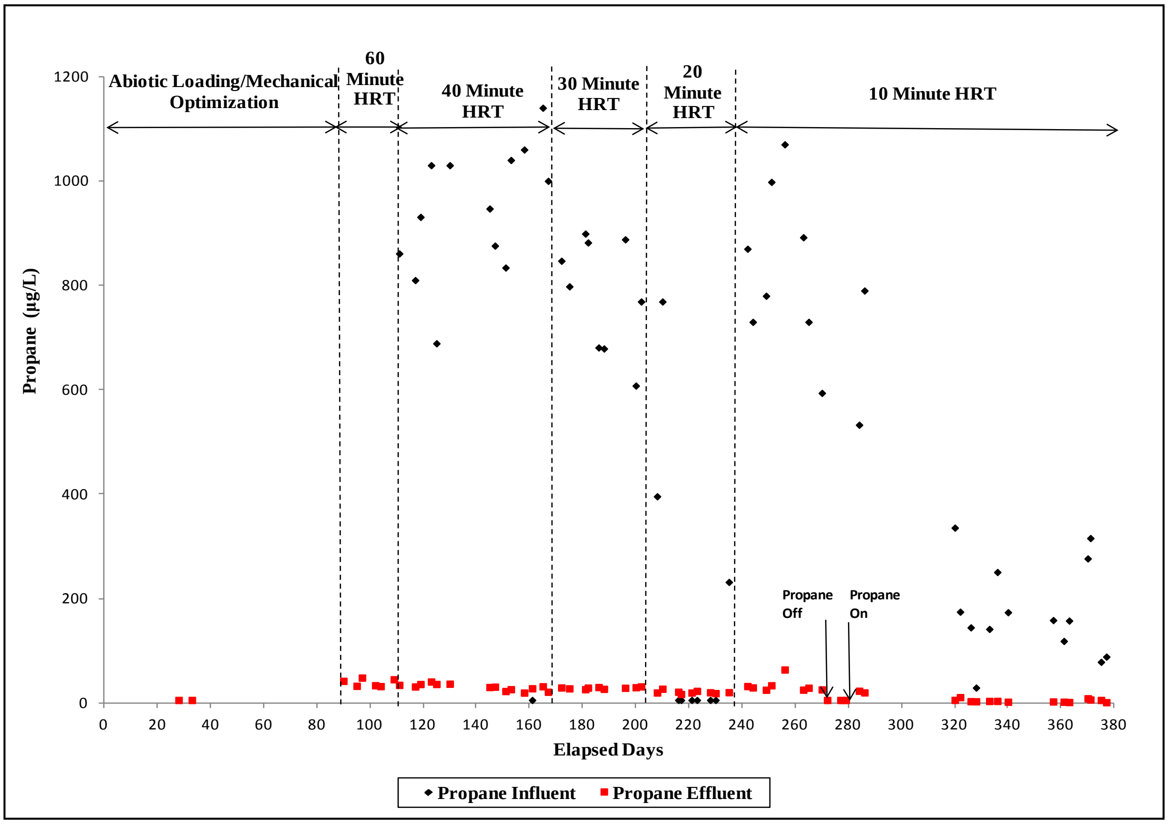
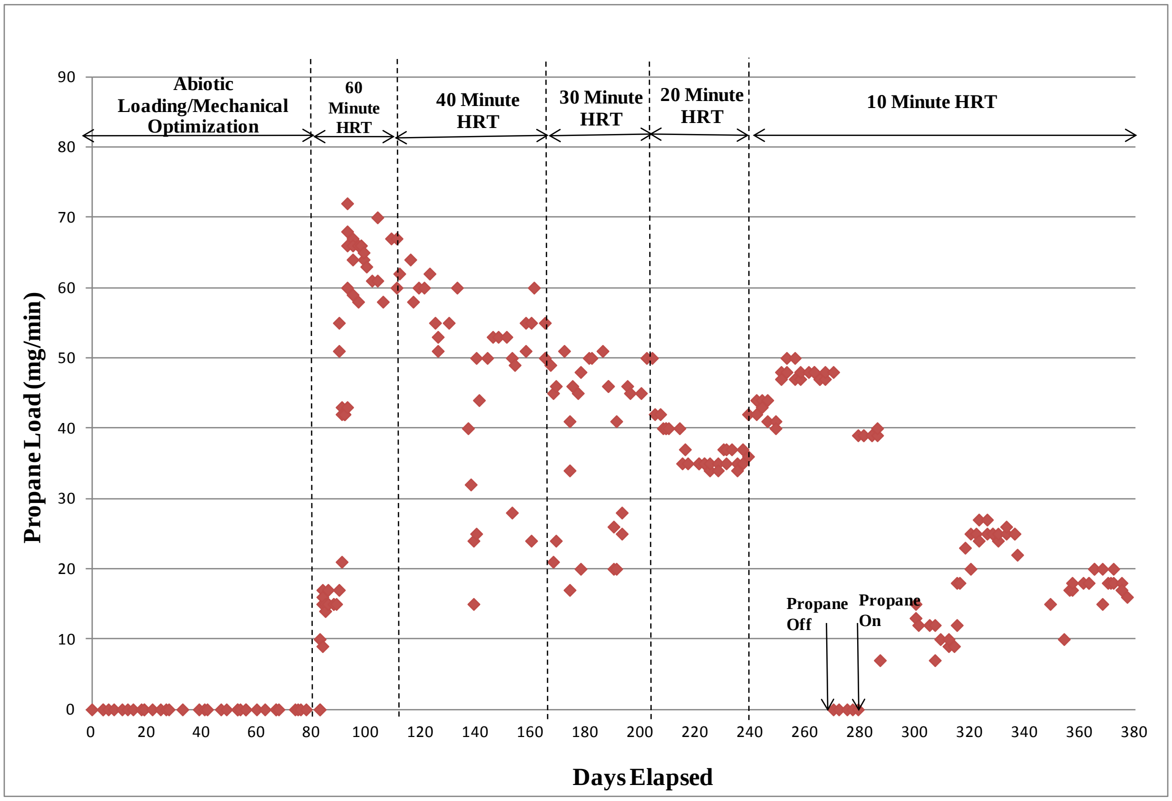


Figure 5.19 Propane load (mg/min) to the FBR system over the duration of the study.

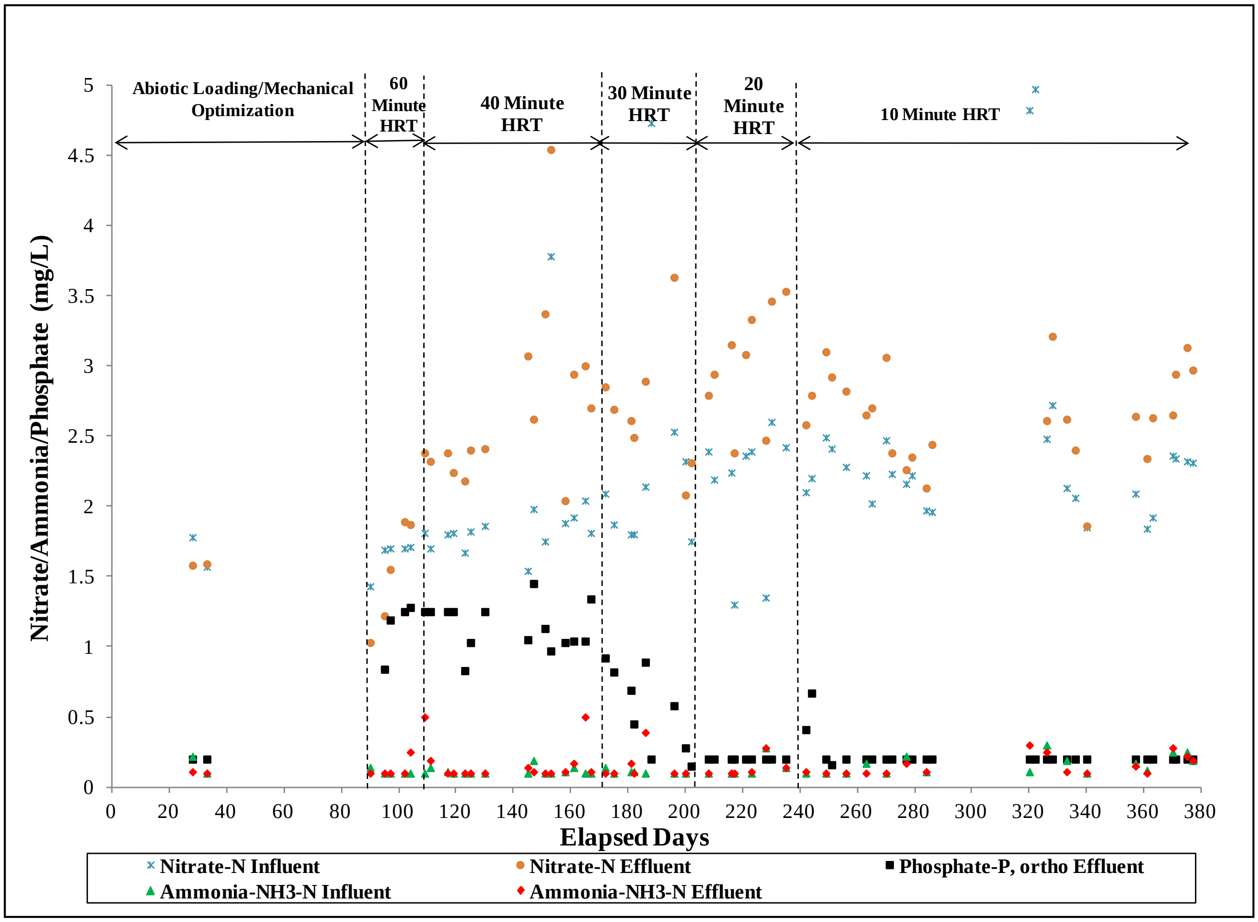


5.7.3 Inorganic Nutrients

Diammonium phosphate and urea were added to the FBR from separate tanks as sources of inorganic nutrients for the propanotrophic bacteria. The original objective was to maintain a slight excess of nitrogen and phosphorus in the effluent. During the test, phosphate was monitored in the effluent by Hach test strips onsite as a quick test and by ion chromatography offsite (IC; EPA Method 300). Upward adjustments to the nutrient feed pump were generally made when the HRT was reduced during the study. The Hach test generally showed effluent orthophosphate-P values between 0.3 and 1.3 mg/L, with an average of 0.8 mg/L over the course of the study (data not shown). The ion chromatograph measurements showed an average excess of 1.1 mg/L from inoculation through Day 203 of operation, when the residence time was reduced to 20 minutes (Figure 5.20), but the effluent values generally declined thereafter, to < 0.2 mg/L. There was a slight discrepancy between the Hach and the IC measurements toward the end of the study (i.e., Hach test showed slight excess and IC did not). The reason for this is unclear. However, the NDMA and DMN data clearly showed that phosphorus was not limiting biodegradation during steady-state operation at the 20 minute and 10 minute residence time.

The concentration of ammonium-N in the effluent was generally below the MDL of 0.1 mg/L based on laboratory measurements (Figure 5.20). Often in aerobic systems such as this, ammonium that is not used as an assimilative N source by bacteria is rapidly oxidized to nitrate by nitrifying bacteria. It should be noted however, that nitrate-N can also be used as a nitrogen source by many strains. The concentration of nitrate-N entering the FBR in the WSTF groundwater over the course of the study averaged 2.2 ± 0.7 mg/L, with a slight upward trend occurring with time. The effluent nitrate averaged 2.7 ± 0.8 mg/L, suggesting that some nitrification of ammonium was occurring in the FBR. This is particularly apparent from Day 90 to Day 239 (the end of the 20 minute HRT). Nitrite, a common intermediate in nitrification, was not detected in any samples at a PQL of 0.2 mg/L. Microbial analysis confirmed the presence of nitrifying bacteria in the FBR, although populations were orders of magnitude lower in density than propanotrophic bacteria (See Section 5.7.6.1).

Figure 5.20 Concentrations of inorganic nutrients in the FBR influent and effluent over the duration of the study.



<u>5.7.4 pH and Temperature</u>

The influent pH to the FBR during the initial phases of the study through about Day 190 (beginning of Phase IV) averaged 8.5 ± 0.3 SU (Figure 5.21). The effluent pH from the FBR during this same time averaged 7.7 ± 0.3 SU. The influent groundwater pH declined after Day 190, averaging 7.3 ± 0.8 SU, which was similar to the pH of the FBR effluent during the same period (7.5 ± 0.7 SU). This drop may reflect differences in the groundwater wells supplying the treatment plant. The pH in the FBR averaged 7.6 ± 0.4 SU over the course of the study based on measurement with an inline sensor. pH control using sodium hydroxide was not required during the course of the study.

The temperature of the feed water and the FBR effluent were pretty similar and showed a slight seasonal fluctuation (Figure 5.22). Over the entire duration of the study, the temperature of the feed water averaged 25.8 ± 3.5^{o}C and that of the FBR effluent averaged 26.0 ± 3.5^{o}C. These temperatures are somewhat higher than those found in more temperate climates in the US. Lower temperatures are unlikely to affect the overall treatment process, although the HRTs may have to be increased somewhat at lower groundwater temperatures.

Figure 5.21 pH in the influent and effluent of the FBR system over the duration of the study.

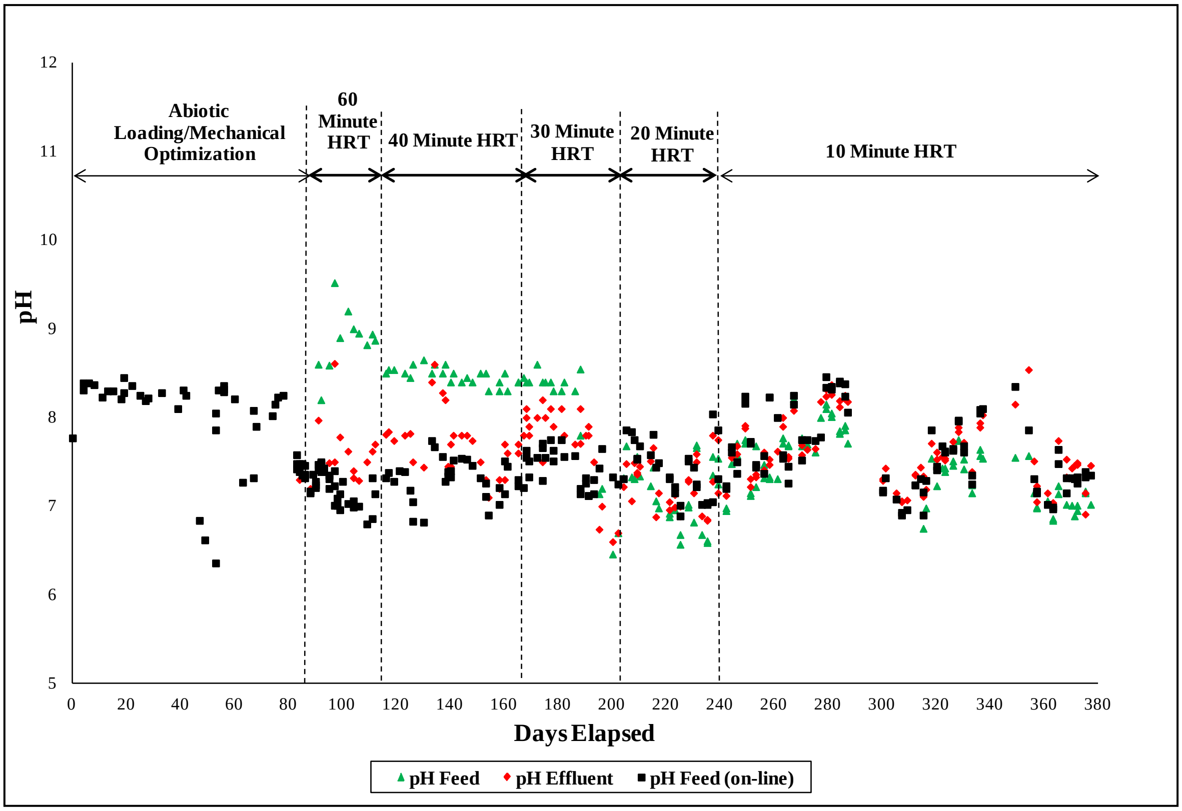
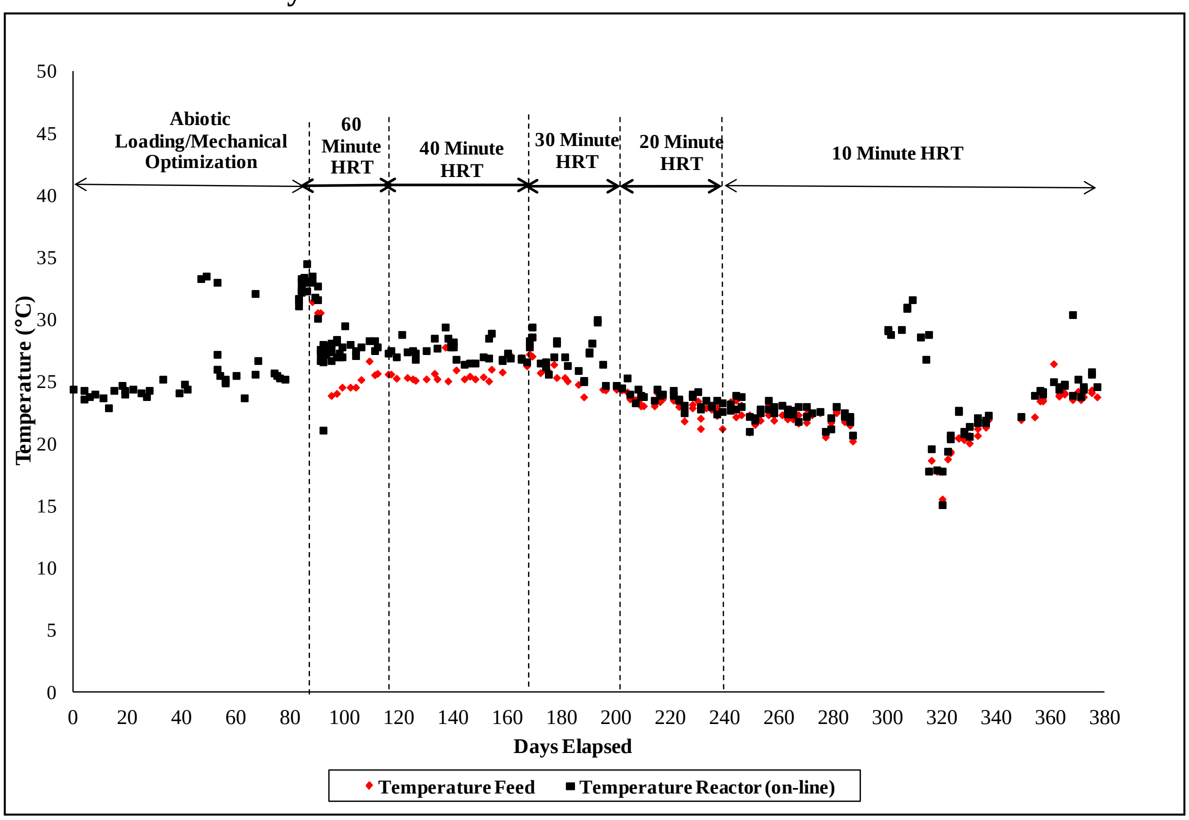


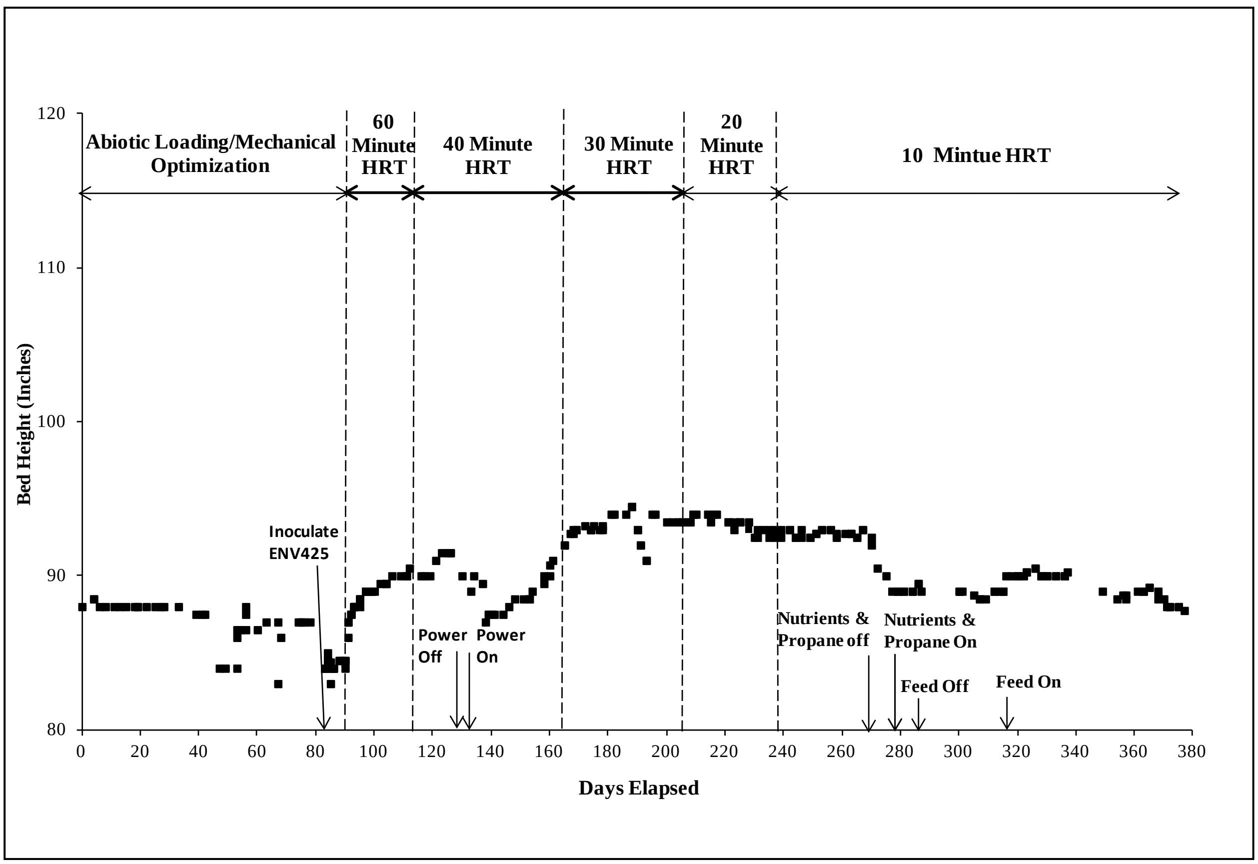
Figure 5.22 Temperature of the influent feed water and water within the FBR system over the duration of the study.



5.7.5 Bed height

The bed height of the FBR averaged 87 ± 2 in while the system was undergoing abiotic loading form Day 0 to Day 83 (Figure 5.23). There was a decline to ~ 84 in during inoculation of the FBR with ENV425 and the subsequent week of recycle to promote cell attachment (Phase II). From Day 90 through approximately Day 126 in Phase III, the bed grew from 84 in to 91.5 in, which would be expected during biofilm formation on the GAC media. The use of the in-bed cleaning device was not necessary to maintain this bed height. After the power was shutdown from Day 130 to Day 134 in Phase III, the bed height declined significantly, reaching 87.5 in on Day 144, before resuming growth. The bed grew for a few weeks, and then stabilized from ~ Day 168 to Day 270 (Phase IV steady-state operation) at 93.1 ± 0.6 in. The bed height declined rapidly when the propane and nutrient feed was shut off from Day 270 – 279, reaching 89 in on Day 277. The bed remained between 88 in and 90.5 in for the duration of the study, which entailed a series of challenge experiments. Bed growth was lower than anticipated based on the laboratory pilot study, but this likely reflects the lower rate of propane addition in the field-scale FBR compared to the laboratory FBR.

Figure 5.23 GAC bed height over the duration of the study.

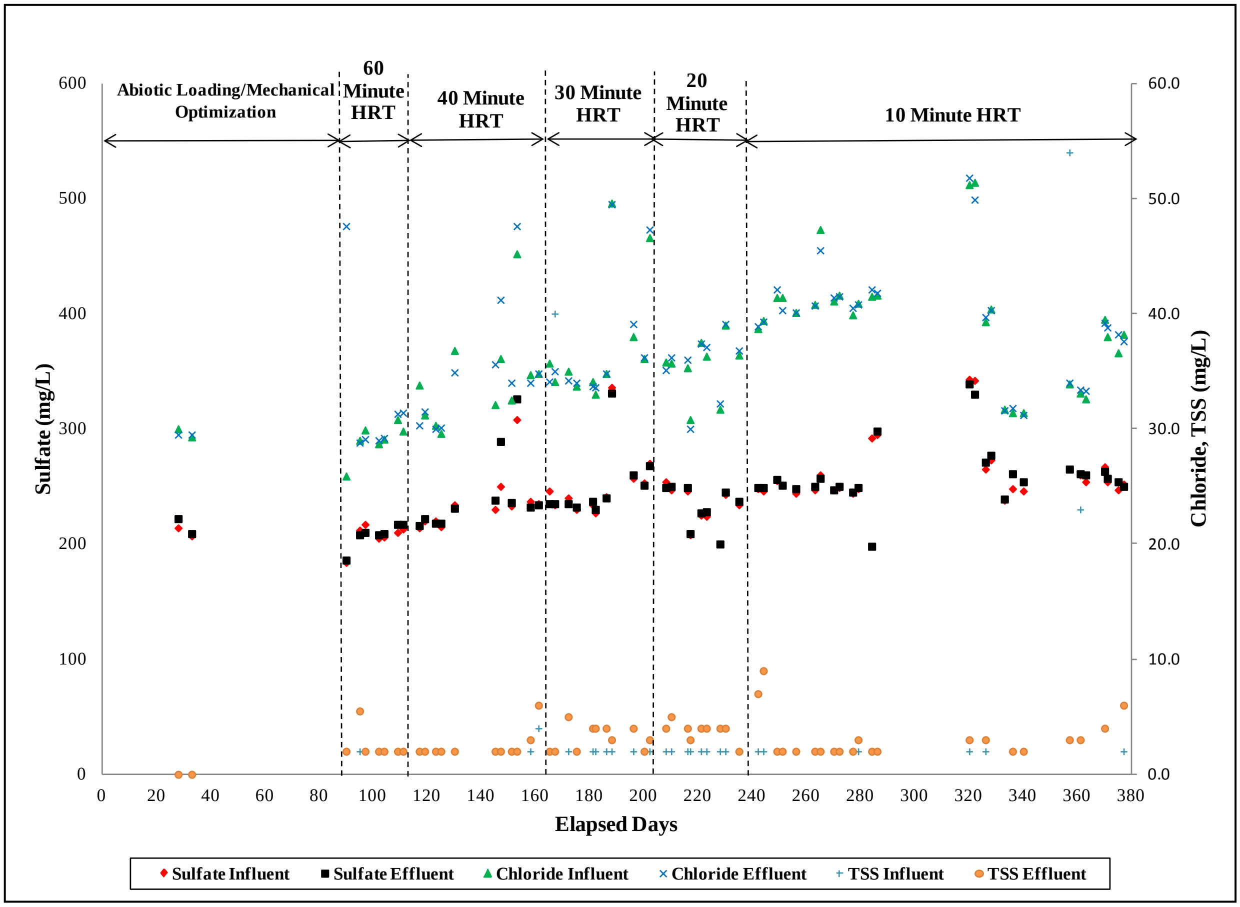


5.7.6 Other Parameters

Other parameters that were measured in the FBR influent and effluent during the demonstration included chloride, sulfate and total suspended solids (TSS) (Figure 5.24). Each of these parameters was relatively steady during the demonstration. Sulfate increased slightly from the

beginning to the end of the study, but averaged 245±31 mg/L over the whole demonstration, which was identical to the average in the influent water (i.e., also 245±31 mg/L; data not shown). One of the advantages of an aerobic reactor system is the absence of sulfate reduction and the resulting sulfide generated by anaerobic processes, which is an odor issue at low concentrations and a health hazard at high concentrations. Like sulfate, chloride in the influent and effluent of the FBR system was unchanged, averaging 36 ± 6 mg/L in the influent and 37 ± 6 mg/L in the effluent. The TSS, which is a means to measure biomass in the FBR effluent was often below the Method MDL of 2 mg/L, and only rarely exceeded 5 mg/L (average 3 ± 1.5 mg/L). Thus, very little biomass was observed to leave the system in the effluent water.

Figure 5.24 Sulfate, TSS, and chloride in the influent and effluent of the FBR system over the duration of the study.



5.7.6.1 Microbial Diversity in the FBR

Samples of GAC from the FBR were analyzed for the dominant microbial populations in the FBR using DGGE with identification of the most prominent bands via 16S rRNA analysis. The analyses were conducted by Microbial Insights, Inc. (Knoxville, TN). The DGGE data for biomass samples collected on Days 112, 249, and 370 are provided in Figure 5.25. Banding patterns and relative intensities of the recovered bands provide a means of comparing the

communities. Bacteria generally must constitute at least 1-2% of the total bacterial community to form a visible band. Labeled bands were excised and sequenced with results provided (Tables 5.8, 5.9, and 5.10). Identifications are based on DNA sequences in the Ribosomal Database Project. Similarity indices above 0.900 are considered excellent, 0.700-0.800 are good, and below 0.600 are considered to be unique sequences.

The DGGE and sequence identification data clearly show that the microbial diversity in the FBR increased significantly over time. On Day 112 (in Phase III), the initial DGGE analysis only showed two bands, the dominant of which was a *Hydrogenophaga* spp., presumably ENV425, which had been inoculated on Day 83 (Figure 5.25; Table 5.8). By Day 249, which was shortly after the HRT was reduced to 10 minutes in Phase IV, the number of bands present on the DGGE gel increased, with four organisms subsequently being identified in the sample from 6 ft and three organisms in the sample from 8 ft in the FBR bed (Figure 5.25; Table 5.9). Interestingly, 6 of the 7 organisms were *Mycobacterium* spp. on the other was a *Hypomicrobium* spp. *Hydrogenphaga* spp. were not present among the most prevalent 3 or 4 bands. *Mycobacterium* spp. include propanotrophs such as *Mycobacterium vaccae* JOB5 (Smith et al., 2003) and others (Wackett et. al., 1989) that have been shown to cometabolize various chlorinated solvents and other contaminants. In fact, during a previous SERDP project, we isolated propanotrophs capable of degrading NDMA from three separate sites in California, New Jersey, and Colorado, respectively, and all were *Mycobacterium* spp. (Hatzinger et al., 2008). Thus, at this phase of FBR operation, it is likely that various Mycobacteria were largely responsible for propane and NDMA degradation. It should be noted, however, that the DGGE/band identification protocol used is not truly quantitative. PCR bias can occur with some bacterial species being identified based on band intensity that are not necessarily representative of the most dominant organisms present. The contribution to NDMA treatment by any of the microbes can't be established based on this analysis only.

Near the end of the demonstration, after all of the challenge testing (and an associated reduction in FBR bed height), the diversity of bacteria was far greater than observed at previous sampling events based on the DGGE gels (Figure 5.25; Table 5.10). Organisms including Gp4 spp., which are Acidobacteria commonly found in drinking water and soils (Novarro-Noya et al., 2013; Yin et al., 2010) and *Haliscomenobacter* spp., which are sheath forming organisms commonly found in activated sludge (Kampfer, 1995), were identified. However, *Mycobacterium* spp., also were prevalent within the FBR, particularly in the 8 ft GAC bed sample. The *Mycobacterium* spp. were most likely those degrading propane and NDMA within the FBR. Some of the increased diversity in the FBR may have resulted from the challenge tests, as well as the reduction in the feed of propane to the FBR. It is possible that some of the organisms near the top of the GAC bed were metabolizing dead biomass within the FBR, consistent with the reduction in FBR bed height during the period of nutrient and propane shutdown. However, the numbers of propanotrophs within the FBR based on gene analysis remained very high throughout the demonstration (see next paragraph).

To quantify numbers of propanotrophs within the FBR, quantitative PCR analysis was conducted targeting the propane monooxygenase functional gene (Microbial Insights; http://www.microbe.com/index.php/CENSUS/census-chlorinated-ethenes.html) on GAC samples collected on Days 249 and 370 (Table 5.11). High numbers of propanotrophs were detected at both sampling

points (> 1 x 10^8 cells/g GAC), with a slight increase from Day 249 to Day 370. In addition to propane-oxidizing bacteria, ammonia-oxidizing bacteria were also present, but at much lower densities than the propanotrophs. Moreover, the numbers declined by about an order of magnitude form Day 249 to Day 370. The ammonia-oxidizing bacteria convert ammonium to nitrate, and likely account for the slight increases in nitrate between the FBR influent and effluent (Figure 5.20). Some ammonia-oxidizing bacteria are also capable of cometabolizing anthropogenic pollutants, such as chlorinated solvents (Ely et al., 1997), and polycyclic aromatic hydrocarbons (Chang et al., 2002). To our knowledge, the cometabolism of NDMA by this group of organisms has not been evaluated.

Figure 5.25 DGGE profile of FBR biomass on three occasions over the duration of the study. Samples (A), (B1 and B2), and (C1, C2, C3, and C4) are from Days 112, 249, and 370, respectively. B1 and B2 are from depths of 6 and 8 feet into the FBR column, while C1-C4 are from depths of 6, 6, 8, and 8 feet, respectively.

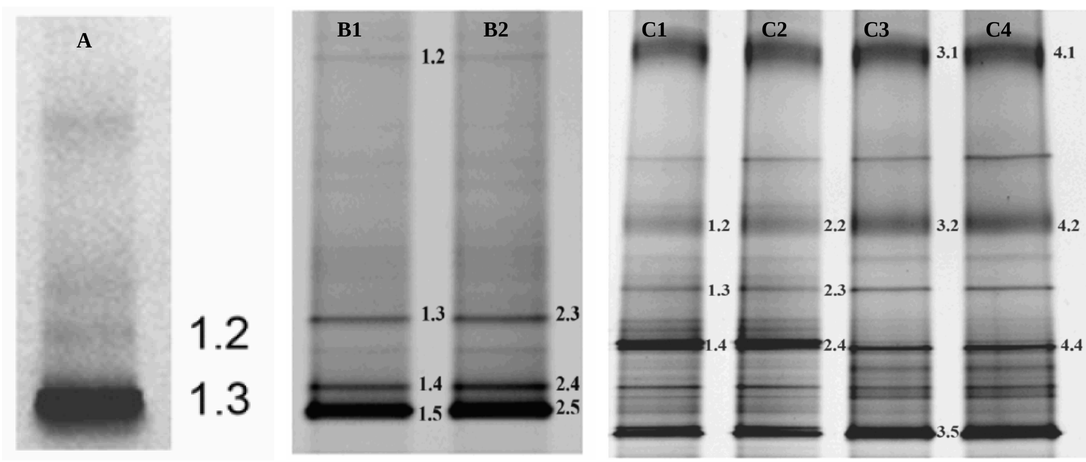


Table 5.8 Sequence results from bands excised from DGGE gel on Day 112, Sample A. The DGGE gel is presented in Figure 5.25.

Band	Similar genus	Similarity Index	Affiliation	Description
1.2	*Uncultured bacterium*	0.81		
1.3	*Hydrogenophaga spp.*	0.96	Betaproteobacteria; Comamonadaceae	Some Hydrogenophaga species can degrade methyl-tert-butyl ether, and some can oxidize carbon monoxide.

Table 5.9 Sequence results from bands excised from DGGE gels on Day 249. Samples B1 and B2 are from 6 ft and 8 ft below the top of the GAC bed, respectively. The DGGE gel is presented in Figure 5.25.

Band	Similar genus	Similarity Index	Affiliation	Description
1.2	*Hyphomicrobium spp.*	0.852	Alphaproteobacteria; Hyphomicrobiaceae	These aerobic bacteria produce stalks that take up diffuse compounds from water sources, and may be useful in bioremediation.
1.3	*Mycobacterium spp.*	0.940	Actinobacteria; Mycobacteriaceae	These aerobic bacteria typically live in water and food sources, although some are obligate parasites. Some species have been shown to degrade PAHs and mineralize vinyl chloride to CO2.
1.4	*Mycobacterium spp.*	0.987	Actinobacteria; Mycobacteriaceae	These aerobic bacteria typically live in water and food sources, although some are obligate parasites. Some species have been shown to degrade PAHs and mineralize vinyl chloride to CO2.
1.5	*Mycobacterium spp.*	0.998	Actinobacteria; Mycobacteriaceae	These aerobic bacteria typically live in water and food sources, although some are obligate parasites. Some species have been shown to degrade PAHs and mineralize vinyl chloride to CO2.
2.3	*Mycobacterium spp.*	0.912	Actinobacteria; Mycobacteriaceae	These aerobic bacteria typically live in water and food sources, although some are obligate parasites. Some species have been shown to degrade PAHs and mineralize vinyl chloride to CO2.
2.4	*Mycobacterium spp.*	1.000	Actinobacteria; Mycobacteriaceae	These aerobic bacteria typically live in water and food sources, although some are obligate parasites. Some species have been shown to degrade PAHs and mineralize vinyl chloride to CO2.
2.5	*Mycobacterium spp.*	0.985	Actinobacteria; Mycobacteriaceae	These aerobic bacteria typically live in water and food sources, although some are obligate parasites. Some species have been shown to degrade PAHs and mineralize vinyl chloride to CO2.

Excised bands not included in this table did not produce phylogenetic matches.

Table 5.10 Sequence results from bands excised from DGGE gels on Day 370. Samples C1 and C2 are replicates taken from 6 ft below the top of the GAC bed. Samples C3 and C4 are replicates taken from 8 ft below the surface of the GAC bed. The DGGE gel is presented in Figure 5.25.

Band	Similar genus	Similarity Index	Affiliation	Description
1.2	*Gp4 spp.*	0.901	Acidobacteria_Gp4	
1.3	*Haliscomenobacter spp.*	0.892	Sphingobacteria; Saprospiraceae	This genus has been isolated from activated sludge and floc.
1.4	*Haliscomenobacter spp.*	0.934	Sphingobacteria; Saprospiraceae	This genus has been isolated from activated sludge and floc.
2.2	*Gp4 spp.*	0.896	Acidobacteria_Gp4	
2.3	*Haliscomenobacter spp.*	0.913	Sphingobacteria; Saprospiraceae	This genus has been isolated from activated sludge and floc.
2.4	*Haliscomenobacter spp.*	0.944	Sphingobacteria; Saprospiraceae	This genus has been isolated from activated sludge and floc.
3.1	*Mycobacterium spp.*	0.904	Actinobacteria; Mycobacteriaceae	These aerobic bacteria typically live in water and food sources, although some are obligate parasites. Some species have been shown to degrade PAHs and mineralize vinyl chloride to CO2.
3.2	*Gp4 spp.*	0.893	Acidobacteria_Gp4	
3.5	*Mycobacterium spp.*	0.998	Actinobacteria; Mycobacteriaceae	These aerobic bacteria typically live in water and food sources, although some are obligate parasites. Some species have been shown to degrade PAHs and mineralize vinyl chloride to CO2.
4.1	*Mycobacterium spp.*	0.823	Actinobacteria; Mycobacteriaceae	These aerobic bacteria typically live in water and food sources, although some are obligate parasites. Some species have been shown to degrade PAHs and mineralize vinyl chloride to CO2.
4.2	*Gp4 spp.*	0.883	Acidobacteria_Gp4	
4.4	*Mycobacterium spp.*	1.000	Actinobacteria; Mycobacteriaceae	These aerobic bacteria typically live in water and food sources, although some are obligate parasites. Some species have been shown to degrade PAHs and mineralize vinyl chloride to CO2.

Excised bands not included in this table did not produce phylogenetic matches.

Table 5.11 Quantification of propanotrophs and ammonia-oxidizing bacteria in the FBR. B1 and B2 are from samples collected from depths of 6 and 8 ft in the FBR bed on Day 249, while C1-C4 are from depths of 6, 6, 8, and 8 feet, respectively, taken on Day 370.

	B1 (cells/g)	B2 (cells/g)	C1 (cells/g)	C2 (cells/g)	C3 (cells/g)	C4 (cells/g)
Functional Gene						
Propane Monooxygenase	9.31×10^8	1.45×10^8	1.64×10^9	1.61×10^9	1.43×10^9	8.61×10^8
Phylogenetic Group						
Ammonia Oxidizing Bacteria	2.94×10^6	3.42×10^6	2.15×10^5	3.15×10^5	5.46×10^4	3.75×10^5

5.7.6.2 GAC Adsorption Study

Extraction of GAC media from the FBR was conducted near the end of the field study to confirm that NDMA removal in the FBR was biological, rather than through adsorption to GAC. A sample of virgin GAC was also prepared and extracted to assess the extraction efficiency of NDMA from the carbon. The virgin GAC adsorbed an average of 347 μg NDMA/g GAC based on mass balance analysis, somewhat lower than that adsorbed during the laboratory study (0.61 mg/g). Of that amount, an average of 241 μg NDMA/g GAC was extracted from duplicate samples, resulting in an extraction efficiency of ~ 70 % (Table 5.12). The quantity of NDMA on the GAC was below detection by the analytical method employed, which had a PQL of ~ 2 mg/L. Based on this PQL the GAC in the FBR was determined to have < 0.13 μg NDMA/g dry GAC on average, which correlates to a maximum of < 0.19 μg/g GAC accounting for the 70% extraction efficiency. Thus, the virgin carbon retained more than three orders of magnitude more NDMA than the FBR carbon. The data indicate that a minimal amount of NDMA was adsorbed on the FBR carbon over the duration of the pilot FBR operation. To corroborate this further, the theoretical loading of the NDMA on the FBR over the course of the study was calculated. For the complete experiment, approximately 4,500,000 L of water was passed through the FBR, with an average influent NDMA concentration of 1.007 μg/L and an average effluent concentration of 0.00785 μg/L. This results in a total of 4.133 kg of NDMA being passed through the FBR. Assuming a total quantity of 57.5 kg of GAC added to the FBR (based on the volume of the GAC added to the FBR and GAC density), the total quantity of NDMA adsorbed to GAC in the FBR, assuming no degradation, would be 0.072 g/g GAC or 72,000 μg/g GAC. This is several orders of magnitude higher than the maximum amount of NDMA adsorbed to the GAC, further confirming that the primary removal mechanism in the FBR is biological degradation rather than adsorption.

Table 5.12 Amounts of NDMA adsorbed to virgin GAC and to GAC removed from the FBR on Day 357.

Sample	GAC mass (dry)	NDMA extracted (μg)	NMDA (μg/g GAC)	AVG μg NDMA/g GAC
V1	24.3	6292	259	241
V2	25.2	5590	222	
F1	31.2	< 3.4	< 0.13	< 0.13
F2	33.8	< 4.2	< 0.12	

6.0 Performance Assessment

The performance of the system during the demonstration included both qualitative and quantitative objectives as described in Section 3.0 and Table 3.1. Each of these objectives is assessed in this section and supported by the detailed sample results provided in Section 5.7.

The general objectives of this FBR treatment system study were to evaluate:

- the ability of *Rhodococcus ruber* ENV425 to effectively colonize the fluidized bed media and achieve an initial NDMA reduction from µg/L to low ng/L (<10 ng/L) concentrations
- the ability of the FBR under steady-state conditions to reduce the NDMA concentrations to less than 10 ng/L at a HRT less than 30 minutes
- the response to plant feed, power, and nutrient interruptions such that a reestablishment of FBR performance to less than 10 ng/L is achieved
- the response to co-contaminant addition such that NDMA concentrations are less than 100 ng/L in the effluent during co-contaminant addition, and returns to less than 10 ng/L treatment upon removal of co-contaminant addition

6.1 Quantitative Performance Objectives

6.1.1 ENV425 Adaptation in FBR upon Start-up

Over the initial five days of operation, operating at a 60 minute HRT, the microbial community established within the FBR system was able to achieve treatment of less than 100 ng/L of NDMA in the effluent of the FBR (Figure 5.12). Within three weeks of start-up, NDMA was degraded from ~1 µg/L down to ~ 10 ng/L in the FBR system. The HRT was modified to 40 minutes, which provided similar results to those observed at the 60 minute HRT. NDMA effluent concentrations slightly spiked with the decrease in HRT, but as the microbial community acclimated to the process change, NDMA effluent concentrations declined below 10 ng/l. As the NDMA effluent concentrations dipped below 4.2 ng/L, the HRT was again modified to 30 minutes and the NDMA effluent concentrations remained at the 4.2 ng/L levels. Based on the results, a microbial community had adapted adequately to the conditions in the FBR during start-up. However, the data suggest that the microbial community in the FBR became increasingly diversified with time, and that several different *Mycobacterium* spp. became the dominant propanotrophs within the FBR with time, displacing ENV425 (Section 5.7.7.1).

6.1.2 Treat NDMA to Below Regulatory Limits/Produce Quality Data

Details concerning the levels of NDMA in the FBR over the duration of the study are provided in Section 5.7.1. From the steady-state operation of the pilot-scale FBR, NDMA treatment requirements below 10 ng/L were met (Figure 5.12). Reductions in hydraulic residence time (HRT) occurred while optimizing the oxygen and propane addition rates. The reduction of NDMA concentrations from 1 µg/L to less than 10 ng/L was indicative of successful treatment. At the 20 and 30 minute HRTs, the FBR system was capable of treating to less than 4.2 ng/L (the most recent modification to the regulatory limit at the site), while at a 10 minute HRT the FBR could consistently achieve NDMA concentrations below 10 ng/L. Hence, the FBR treatment

system was demonstrated to be an effective means to treat 1 µg/L concentrations of NDMA consistently to less than 10 ng/L and, when further optimized, concentrations below 4.2 ng/L were achieved. The most effective operational parameters for this pilot-scale demonstration were:

- A 20 minute hydraulic residence time
- An oxygen addition rate of 175 mg/min
- A propane addition rate of 35 mg/min (28.6 mg C/min)
- A diammonium phosphate addition rate of 30 mL/min at 110 mg/L
- A urea addition rate 31 mL/min at 352 mg/L

During steady-state operation, the oxygen and propane residuals in the FBR effluent averaged greater than 4 mg/L and ~ 30 µg/L, respectively. The settings for oxygen and propane were modified to ensure that an explosive environment was not produced in the headspace of the FBR, while still allowing for full treatment to occur. Compared to the bench-scale study, the levels of propane in the effluent were an order of magnitude lower. Hence, lower residual propane addition rates were achievable. Details concerning the levels of oxygen and propane in the FBR over the duration of the study are provided in Section 5.7.3.

To ensure that all the data collected and reported was valid in demonstrating that the plant met the NDMA regulatory standards, extensive quality assurance and quality control measures were undertaken. Per the QAPP, the completeness objective for all validated data was 95 percent. For the off-site laboratories, a total of 226 samples were submitted for analysis of NDMA. Of these 226 samples, two points on Day 27 were flagged (one influent and one effluent sample) because the sample hold time was exceeded by one day. However, these data points were not removed from the data set. The percentage completeness for the NDMA analysis was 98%. For all other chemical parameters measured, the completeness objective of 95% was met.

Twelve percent of off-site analytical laboratory samples were collected with appropriate quality control samples. On Days 223, 230, and 256, quality control samples for NDMA analyses were collected and analyzed (Table 6.1). The results indicated that at the low ng/L concentrations detected in the effluent, small differences between the splits and duplicates became magnified, increasing the relative percent difference (RPD). Such magnification did not occur to a similar degree for the feed results. In addition to the quality control samples, split samples for effluent NDMA analyses were collected on days 244, 284, and 370 and sent to two different laboratories (SRI and Weck) for a quality assurance comparison (Table 6.2). For the NDMA effluent samples sent to the SRI laboratory, one liter amber bottles were collected, and the low level HRMS NDMA method was used for analysis. For the NDMA effluent samples sent to the Weck laboratory, one liter amber glass bottles were collected with no chemical additives and two 500 mL bottles were collected with sodium thiosulfate added as a quenching agent for any residual chlorine in water samples. This chemical is used in Method 521 primarily to prevent the formation of NDMA from residual chlorine in water samples that may react with secondary amines or other N-containing compounds. The samples with and without sodium thiosulfate were analyzed using EPA method 521.

The results from effluent NDMA samples collected on Day 244 showed a discrepancy between for the samples with and without sodium thiosulfate (Table 6.2). The NDMA concentration in samples with the sodium thiosulfate (Weck) was 0.025 ng/L, compared to 0.0023 ng/L (Weck) and 0.0037 ng/L (SRI) in samples without added sodium thiosulfate. To determine the cause of the discrepancy, on Day 284, additional split effluent NDMA samples were collected and again sent to both labs. However, for this sampling event, additional samples were sent to Weck labs to compare with the SRI results of same sample. The extra samples sent to Weck included two 500 mL bottles with sodium thiosulfate that were filled with distilled water and another set of 500 mL bottles triple rinsed with distilled water and then again filled with distilled water. Also, one set of 500 mL bottles were triple rinsed with distilled water and then filled with a split effluent sample. On day 370, the same type and number of samples were collected as on day 284 to verify the results from both laboratories/methods, but new bottles were used for this sampling event. From the results, it was concluded that the presence of sodium thiosulfate artificially elevated NDMA results in samples collected on day 244 that contained this compound (analyzed by Weck). The bottles filled with distilled water plus sodium thiosulfate had 0.024 μg/L of NDMA whereas bottles that had the sodium thiosulfate rinsed out prior to filling with distilled water had < 0.002 ng/L NDMA. On day 370, when new bottles with sodium thiosulfate were ordered from the laboratory, samples with and without the added quenching agent had similar concentrations. Thus, it appears that the thiosulfate added to the bottles used for sample collection on days 244 and 284 (same batch of bottles) was contaminated with small amounts of NDMA. This issue in no way affects the analytical results for the project because none of the routine samples analyzed by HRMS received sodium thiosulfate.

The relative percent difference values between the various effluent NDMA samples demonstrated a range from 47%-63%. The significance in the discrepancy between labs is difficult to quantify because the measured values are very close to the method detection limit (MDL). Blind samples were not submitted due to the limitations of the respective laboratories sample preparation procedures. These procedures required that the level of NDMA be approximately known upon arrival at the lab so that appropriate dilutions and analytical techniques could be utilized.

On day 217, quality control samples were collected and analyzed for chemical parameters of anions, propane, VOCs, and ammonia. Sample influent duplicates were collected along with effluent split samples, trip blank for VOCs, and field blanks. Over the course of the demonstration, the following number of total samples for analysis of different parameters were collected:

- 264 samples for analysis of propane
- 324 samples for analysis of VOCs
- 138 samples for analysis of anions
- 126 samples for analysis of TSS
- 106 samples for analysis of ammonia

The results generally showed small differences between the original influent sample and duplicate. For the effluent splits samples, small differences also were observed except for bromide and propane, which were somewhat lower in the splits, causing a decrease in RPD (data not shown).

Table 6.1 Pilot-Scale study sample and quality control sample results for NDMA analysis and the calculated relative percent difference values (RPD, NM= Not Measured).

Days Elapsed	Feed Sample (µg/L)	Feed Collection Duplicate (µg/L)	Feed Collection Duplicate RPD	Field Blank (µg/L)	Feed Duplicate Filtered (µg/L)	Feed Duplicate Filtered RPD		
223	0.85	0.84	1.18	NM	NM	NM		
230	1.25	NM	NM	0.01	NM	NM		
256	0.66	0.74	-11.43	NM	0.69	-11.43		
Days Elapsed	**Effluent Sample (µg/L)**	**Effluent Collection Duplicate (µg/L)**	**Effluent Collection Duplicate RPD**	**Field Blank (µg/L)**	**Trip Blank (µg/L)**	**Effluent Field Split Duplicate (µg/L)**	**Effluent Split Duplicate (µg/L)**	**Effluent Split Duplicate RPD**
223	0.00273	NM	NM	NM	0.00308	NM	NM	NM
230	0.00183	0.00342	-60.57	0.01	NM	0.00179	0.0041	-78.44

Table 6.2 Comparison of NDMA effluent results (µg/L) from two analytical labs.

	With Thiosulfate	Without Thiosulfate	With Thiosulfate	Without Thiosulfate	With Thiosulfate	Without Thiosulfate
Days Elapsed	244	244	284	284	370	370
Weck Labs	0.025	0.0023	0.035	0.0036	0.0027	0.004
Southwest Research Inst. (SRI)	NM	0.0037	NM	0.00593	NM	0.0077
DW[1] Field Blank (Weck Labs)	NM	NM	0.024	<0.002	<0.002	<0.002
Percent Difference Between Labs	148.432	46.667	142.047	48.898	96.154	63.248

[1]DW, distilled water

All water chemistry analytical data were reviewed to determine if any data points were statistical outliers in the data set, thus requiring them to be evaluated further. Performing the statistical Grubb's outlier test (http://www.sediment.uni-goettingen.de/staff/dunkl/software/pep-grubbs.pdf) on all data points, using a value of false rejection of 5%, several data points statistically exceeded the critical Grubb's T-test for outliers (calculated T-value exceeded T-test critical value, Table 6.3). For all of the NDMA samples analyzed, three influent data points on days 82, 153, and 320 and two effluent data points on days 91 and 361 were flagged and investigated further to determine if they should be discarded from the data set for statistical reasons. For the two NDMA effluent data points statistically highlighted as outliers, it was observed prior to sampling that the system experienced a system feed shut down and restart. Interruption in system feed flow likely contributed to the higher effluent NDMA reported and the statistical designation of these points as outliers. For all other chemical parameters, Tables 6.4-6.9 show data points that were statistically flagged as outliers by the Grubb's T-test. Most effluent values that were statistically highlighted as outliers from the data set were influenced by the system experiencing a feed or power shut down and feed or power restart prior to sampling. As a result, no data points were removed from the data set based on the statistical test, but those points are indicated in the subsequent tables.

Table 6.3 NDMA sample results detected as outliers.

Days Elapsed	Reported Value (µg/L)	Average Value (µg/L)	Standard Deviation (µg/L)	Calculated T-Value	Grubb's T-Test Critical Value
82	1.13	1.018	0.074	3.182	1.67
91	0.110	0.034	0.035	2.159	1.94
153	2.610	1.244	0.480	2.848	2.33
320	1.460	0.914	0.193	2.827	2.72
361	0.01422	0.0062	0.0025	3.175	2.72

Table 6.4 Ortho-Phosphate sample results detected as outliers.

Days Elapsed	Reported Value (mg/L)	Average Value (mg/L)	Standard Deviation (mg/L)	Calculated T-Value	Grubb's T-Test Critical Value
90	7.08	2.02	2.236	2.626	1.94
242	0.46	0.219	0.0587	4.11	2.66
244	0.67	0.224	0.098	4.538	2.68
251	0.5	0.229	0.079	3.428	2.68

Table 6.5 Nitrate sample results detected as outliers.

Days Elapsed	Reported Value (mg/L)	Average Value (mg/L)	Standard Deviation (mg/L)	Calculated T-Value	Grubb's T-Test Critical Value
90	1.43	1.677	0.117	2.12	1.94
153	3.78	1.988	0.58	3.091	2.29
153	4.54	2.766	0.692	2.564	2.29
188	4.73	2.284	0.898	2.725	2.18
188	5.66	2.991	1.023	2.608	2.18
320	4.82	2.307	0.556	4.523	2.68
320	5.46	2.755	0.64	4.223	2.68
322	4.97	2.405	0.748	3.428	2.7
322	5.62	2.861	0.836	3.301	2.7

Table 6.6 Sulfate sample results detected as outliers.

Days Elapsed	Reported Value (mg/L)	Average Value (mg/L)	Standard Deviation (mg/L)	Calculated T-Value	Grubb's T-Test Critical Value
90	184	206.714	10.828	2.0978	1.94
90	186	207.857	10.415	2.099	1.94
153	308	236.83	25.153	2.829	2.29
153	326	241.25	32.852	2.57	2.29
188	336	252.2	32.365	2.589	2.18
188	331	251.9	30.538	2.59	2.18
320	343	262.22	26.809	3.013	2.7
320	339	260.296	26.82	2.935	2.7
322	342	259.115	21.827	3.797	2.68

Table 6.7 Chloride sample results detected as outliers.

Days Elapsed	Reported Value (mg/L)	Average Value (mg/L)	Standard Deviation (mg/L)	Calculated T-Value	Grubb's T-Test Critical Value
90	25.9	29.029	1.549	2.02	1.94
90	47.6	32.343	6.818	2.238	1.94
153	45.2	34.4	4.118	2.622	2.29
153	47.6	34.842	5.076	2.513	2.29
320	51.8	39.5	4.924	4.398	2.7
340	31.2	39.5	4.924	2.952	2.7

Table 6.8 Propane sample results detected as outliers.

Days Elapsed	Reported Value (µg/L)	Average Value (µg/L)	Standard Deviation (µg/L)	Calculated T-Value	Grubb's T-Test Critical Value
111	861	128.1	323.16	2.268	1.94
161	6	866	298.9	2.877	2.29
167	21.7	28.57	2.903	2.367	2.18
210	76.9	159	267.874	2.276	2.11
210	27.5	21.244	2.867	2.182	2.11
256	64.3	14.713	14.928	3.322	2.7

Table 6.9 TSS sample results detected as outliers.

Days Elapsed	Reported Value (mg/L)	Average Value (mg/L)	Standard Deviation (mg/L)	Calculated T-Value	Grubb's T-Test Critical Value
90	20	11.4	3.8	2.27	1.94
90	20	10.8	4.4	2.10	1.94
158	2	8.8	2.8	2.48	2.29
158	3	10	2.2	3.13	2.29
167	40	12.2	10.1	2.76	2.18
167	10	4.1	2.3	4.48	2.18
235	10	4.7	2.1	2.59	2.11
357	54	10.9	10.9	3.95	2.58

6.1.3 Effects of Interruptions on FBR Operation

Challenge experiments were conducted to determine the ability of the technology to rebound from electron donor and nutrient feed interruptions, feed flow interruption, and system shutdowns. For all of the interruptions, re-establishment of FBR performance to less than 10 ng/L of NDMA at the plant effluent within 24 hours of system restart was targeted. When the plant reached steady-state, the interruption of electron donor and nutrients did not have any negative impact when the system was restarted nine days later. NDMA effluent concentrations were below 4.2 ng/L. Presumably, the biomass was able to survive/thrive the shorter interruption by utilizing the supply of residual TOC, dead cells, and/or other nutrients available (nothing was added). If the experiment was conducted longer (i.e., 30 days), the same results may not have been observed. For the feed and system shutdowns during steady-state operation, results generally indicated that the FBR could recover to treatment levels below 10 ng/L in 24 hrs to 4 days. During the 20-30 minute HRT, effluent concentrations < 4.2 ng/L of NDMA were observed consistently upon system restart. Again, this may be a function of the length of the interruption. However, even at 28 days of a feed interruption, the system was capable of treatment to less than 10 ng/L within five days (when samples were first collected). The target objective of 24 hours was realized depending on the length of the shutdown and subsequent restart.

6.1.4 Effects of Co-Contaminants on NDMA Treatment

Treatment of NDMA to less than 100 ng/L in the presence of site co-contaminants was the objective. Before removing the air stripper bypass, NDMA effluent concentrations were approaching 4.2 ng/L at the 10 minute HRT (Figure 5.12). After removing the bypass, initial data demonstrated NDMA effluent concentrations increasing above 10 ng/L (to 14 ng/L at one point), but the effluent NDMA concentrations continued to decline over the course of the experiment to approximately 5 ng/L. Some reduction in Freon 11 was observed during this experiment, but that likely reflects adsorption to the GAC matrix. TCE was reduced to < 1 μg/L, which may have been the result of a combination of adsorption and biodegradation. Treatment of TCE in aerobic environments has been previously observed via cometabolic pathways by other researchers (Malachowsky et al., 1994; Alvarez-Cohen and McCarty, 1991; Wackett et al., 1989). However, during this experiment, the co-contaminants were added over a fairly short duration and at such low concentrations that adsorption to the carbon media bed may have been a contributing removal mechanism. These experiments provided data corroborating the treatability study results and demonstrating minimal effect from the presence of co-contaminants in the FBR feed water on NDMA treatment.

6.1.5 Assess Treatment of DMN

Treatment of DMN to < 10 ng/L in the FBR at an HRT value of 20 to 30 minutes was the objective. The treatment objective was met. DMN was treated to ≤10 ng/L from Day 97 to Day 270, when the propane and nutrient feed was shut off. DMN increased to 46 ng/L by Day 279 when the gas and nutrient addition was reinitiated. The concentration remained at 47 ng/L on Day 286, but declined thereafter, falling to < 10 ng/L from Day 320 to the end of the study on Day 377.

6.2 Qualitative Performance Objectives

6.2.1 Ease of Use

Minimal operator attention of ten hours per week was considered ideal for such a system. This included collecting operational data, filling chemical drums, and checking on basic water chemistry. Efforts (i.e., time required) of sample acquisition for this pilot-study beyond what would be required for a full-scale system were accounted for when determining if the success criteria were met. The minimal operator attention of about ten hours a week (2-4 hours per day, 3 times a week) was maintained overall during the demonstration.

During the treatability study, one area of labor-sink in terms of the operator attention was manually limiting bed expansion, but this was not an issue observed in the pilot-study. A second labor-sink was the continual manual adjustment of the oxygen and propane addition rates to the system. This second action was minimized at the pilot-scale by the use of a flow controller that was temperature sensitive. Since more accurate, lower levels of oxygen and propane were added to the system, less biomass formed which allowed for improved bed control. Thus, a key finding from this study is that the lower gas addition rates ultimately lead to less operator attention necessary for the system.

6.2.2 Reliability

The ability for the system to continuously operate is critical. Hence, greater than 90% uptime reliability was the target goal. In those circumstances when intentional interruptions or manual changes in system operation were encountered, such breeches in reliability were not incorporated into the system uptime calculation. The largest upsets to the system that occurred were caused by equipment failure from the fluidized pump (pump 102) and air compressor on Days 130 and 354, respectively. A secondary upset was when power outages were caused by lightning storms in the area (Day 186). A third upset was caused by UV shut down for maintenance causing system feed to be off (Day 195). Even with these system interruptions, quick resolutions to the problems were generally enacted and the system brought back on line. This resulted in 94% uptime being achieved, demonstrating that the system was reliable. In terms of the full-scale, as a precaution, it is advisable to include a spare fluidization pump as a requirement since this item can have a long lead time to replace.

6.2.3 Reduction of Treatment Costs

During the demonstration, multiple FBR HRTs were evaluated to determine the maximum capacity of the system to achieve regulatory NDMA requirements. During this testing, nutrient/propane/oxygen addition rates were adjusted while still maintaining effluent NMDA concentrations of less than 10 ng/L NDMA at the effluent of the FBR. Every attempt was made to minimize these chemical addition rates, the system electricity requirements, and operator attention/maintenance. Based on the findings, a 20 minute HRT produced optimal conditions for the FBR system to meet regulatory regulations for NDMA treatment to below 10 ng/L and even the more stringent 4.2 ng/L requirement that was instituted for WSTF after the initiation of this project. So, the optimal operating parameters were determined to be:

- 20 minute hydraulic retention time
- An oxygen addition rate of 176 mg/min

- A propane addition rate of 35 mg/min (28.6 mg C/min)
- A diammonium phosphate addition rate of 35 mL/min at 110 mg/L
- A urea addition rate of 36 mL/min at 352 mg/L

Using these optimal operating parameters, the FBR treatment costs have been developed and are provided in comparison with a competing technology in Section 7.0.

7.0 Cost Assessment

The pilot-scale FBR treatment system operation was demonstrated for approximately a one year period (March 8, 2012 through March 20, 2013). The current technology of choice for NDMA treatment is UV irradiation. NASA WSTF has installed a 125 gpm Mid-Plume Intersection and Treatment System (MPITS) with UV being the primary treatment mechanism. For the FBR technology, its cost-effectiveness is directly correlated to the system HRT. At the HRT of 20 minutes, the NDMA feed was treated effectively from feed concentration of ~1 μg/L to an effluent concentration of $\leq$ 4.2 ng/L. Hence, during the course of the demonstration, a number of variables were tracked to further understand their cost implication as the FBR technology would be scaled from 2.2 gpm (20 minute HRT) to 125 gpm.

7.1 Cost Model

A cost model has been developed and is provided with the necessary cost elements of the FBR treatment system that are required for implementing the technology at full scale at < 5 gpm (Table 7.1). A number of assumptions and caveats are required. The installation costs provided are only applicable for systems in this size range (< 5 gpm) being implemented as a pilot-scale demonstration. For larger systems, though scaling of the costs may be directly proportional in some cases (i.e., electrical design), costing is not always directly scaled. For instance, for this demonstration, the concrete pad and building already existed as they formed the basis of the infrastructure for the MPITS. Hence, the costs for these items are not applicable in this specific case. The concrete pad and building requirements for a scaled-up FBR may be different than the existing UV system. For much larger installations, significantly more design, labor, and materials would be required. Although a cost reduction might be observed based on an economy of scale, this reduction may be offset by the need for larger delivery trucks, fuel fees, additional labor, etc. These differences are not accounted for in the cost model and are typically calculated on a case-by-case basis. An detailed cost comparison between a UV system and an FBR operated at 125 gpm over a 30 year life cycle is also presented (Section 7.3 and Table 7.2).

Additional caveats must be realized with the costs presented because the associated labor and monitoring costs were a direct result of the number of scientific experiments that were conducted specifically for the ESTCP evaluation. This level of labor and monitoring effort would not be required for a typical operating system of any scale. Finally, like all system plant start-ups, typically the initial two to three months of operation require more troubleshooting and are more labor intensive. Hence, the first year of labor required is greater than subsequent years of operation. For the cost model presented in Table 7.1, estimated costs for designing and operating an FBR at the scale of this demonstration (< 5 gpm) are presented. In several instances, the costs presented differ from those actually incurred during this project for a variety of reasons, including significant delays after system installation due to issues with the MPITS facility, the fact that the FBR pilot-unit used for the demonstration had been previously constructed, and was modified for this effort rather than built for scratch, and that a long-term study was performed with a laboratory-scale FBR before the field demonstration to establish operating conditions. Table 7.1 estimates the cost of designing and operating a new FBR at the scale provided, and relevant subsections discuss some of the differences between the costs in the ESTCP research project and those expected for a typical commercial application.

7.1.1 Treatability Study

Significant bench-scale treatability testing as conducted in support of this ESTCP demonstration, including various microcosm tests to evaluate NDMA degradation in batch and a long-term laboratory FBR study the results of which were published separately in Webster et al., (2013). The estimated cost of this scale of laboratory study is \$231,000. For this ESTCP application, the laboratory FBR study was conducted to evaluate whether it would be possible to treat NDMA to < 10 ng/L in an FBR, and to assess FBR operation, including gas addition rates, bed height growth and control, pH adjustment, nutrient requirements, etc. For future applications, it would likely not be necessary to conduct a similar study (although cost is included in Table 7.1), which would significantly reduce this cost element. Small-scale microcosm testing would always be recommended, primarily to ensure that the geochemical conditions and/or co-contaminants were not toxic to propanotrophic bacteria. However, this testing would be anticipated not to exceed 15k.

7.1.2 Project Management & Design

This ESTCP demonstration involved designing, engineering, and fabricating a "first-of-its kind" complete biological NDMA treatment system using propane as a cometabolic substrate. Hence, project management and design costs are significantly influenced by the labor required to implement this initial system. In addition, a number of management tasks were associated with this project that were the result of delays in the start-up of the system. The equipment arrived in August, 2010, but was not permitted to be operated until March, 2012. Such delays required the retraining of personnel and additional oversight of activities at the site that were not planned. Thus, these costs were higher than would be expected for a typical application of this technology at a new site. The estimated \$63,000 for system design, procurement, reporting and administration presented in Table 7.1 represents estimated costs for design of a small-scale FBR assuming knowledge of the results of this demonstration, and none of the project delays that occurred during this effort.

7.1.3 Fabrication & Equipment

The associated costs for the fabrication of the FBR treatment system included both the use of in-house labor for the FBR and associated controls, as well as subcontracted vendors for programming and electrical. The pilot-test equipment already existed prior to this study, but significant overhaul of the unit was necessary to make it operable for this specific application. This overhaul included upgrading the PLC computer, modifying the gas delivery systems, implementing gas monitoring safety considerations, and retrofitting many of the feed, fluidization, and metering pumps. Since this pilot-scale system already existed, the cost for fabrication is not directly scalable to larger systems. However, the estimated cost for a 1 ft diameter FBR system of $\leq$ 5 gpm that is fabricated as a new unit, including all necessary controls is \$235,000 (Table 7.1). In addition, the estimated cost for the fabrication of a full-scale system operating at 125 gpm is provided in Table 7.2 (Section 7.3).

7.1.4 Installation

The majority of the installation was conducted by the personnel at WSTF with supervision by Envirogen and Shaw personnel. Since a concrete pad, electrical, piping, and a building already existed at the MPITS, the costs to install the actual pilot-scale equipment were minimal in comparison. An estimate for installation of a newly fabricated system at the site is \$6,400 for

shipping, \$10,600 for travel and incidentals, and \$20,000 for all labor and installation materials. Estimates of similar costs for a full-scale FBR system designed to operate at 125 gpm are provided in Section 7.3 based on a number of prior installations.

Table 7.1 Cost model for small-scale FBR implementation (<5 gpm).

Element	Data Tracked During the Demonstration	Description	Cost
Treatability Study/Baseline Characterization	•NDMA Treatment in WSTF water and in a bench-scale system	Year 1 of study	\$231,000
Project Management	•Coordination of system design, procurement, reporting, administrative	Inclusive for only the pilot-scale study	\$63,000
Design Fabrication & Equipment	•FBR system	Equipment cost-New Unit	\$235,000
Installation	•Shipping cost, rigging, unloading (roundtrip)	Memphis, TN to Las Cruces, NM	\$6,400
	•Travel and incidentals required to work on site	Hotels, per diem, mileage, rental vehicles	\$10,600
	•Labor and materials required for installation of reactor, piping and electrical	Multiple projects served at the site, two man crew	\$20,000
Operation and Maintenance	•Chemicals and consumables required (propane, oxygen, nutrients) for plant operation	Chemicals, consumables	\$15,000
	•Laboratory supplies, analytical instrument supplies for monitoring	Test kits, glassware	\$5,000
	•Labor required	Field Engineer, 10 hrs/wk	\$31,000
		Project Manager, 4 hrs/wk	\$19,000
	•Electricity required	Not able to measure	\$1,000
Monitoring	•Laboratory analytical services	Analytical	\$107,000
Waste Disposal	•Trash service	Rental/haul away on monthly basis	\$1,000

7.1.5 Operation and Maintenance

7.1.5.1 Materials Required

During the course of the demonstration, the FBR treatment system was operated in continuous forward feed mode. Chemicals were continually added to the treatment process to ensure that the NDMA was treated to low levels. These chemicals included propane grade 2.0, 99% purity and zero-grade oxygen 2.8 (Airgas, Las Cruces, NM) in separate pressure vessels. In addition, diammonium phosphate (110 mg/L) and urea (Sigma-Aldrich, St. Louis, MO; 352 mg/L) were added as inorganic nutrients. Usage was tracked on a monthly basis and the costs for the one year demonstration were reported. Chemical costs and consumables were approximately \$15,000, and field laboratory supplies for onsite monitoring were approximately \$5,000.

Presumably, significant cost reductions would be observed for larger quantity purchases. Volumes of chemicals can be considered linearly scaled with feed flow being treated, but the associated costs actually are reduced per kilogram of NDMA treated because of the reduction in bulk chemical costs.

7.1.5.2 Labor

A portion of the costs associated with the operation and maintenance (O&M) of the 5 gpm plant are applicable to a plant of a much larger size (i.e., 125 gpm). The issues encountered at the demonstration plant during start-up and operation would likely be observed and resolved in a similar manner at a much larger scale plant. Hence, the manpower and time required during start-up can be considered conveyable at either scale of plant. The manpower utilized during this demonstration after start-up issues were resolved was primarily utilized for performing a variety of experiments that would not necessarily be required on a day-to-day operation of a much larger full-scale plant. For more routine operation of a 5 gpm plant, it is anticipated that the labor costs for system O&M would include 10 hrs per week for a field technician (estimated at $31,000 per year of operation) and 4 hrs per week for a project manager (estimated at $19,000 per year). For a scaled-up plant, O&M costs must be carefully evaluated on a case-by-case basis.

A few caveats must be noted regarding the O&M cost values presented:

- The start-up process of any water treatment plant will typically require significantly more labor until the mechanical, electrical, and process issues are addressed and remedied. From experience, this process can take from 2 to 4 months depending on the complexity of the process. A significant gap in start-up and operating labor costs for different size units will be negligible if the complexity of the systems is similar. This assumption is valid in scaling up from 5 gpm to 125 gpm.
- The labor costs associated with the plant operation in the field are derived based on industry standards for a service contractor to conduct the operation. A licensed water treatment plant operator did not service this plant during the study. Rates for another facility will differ based on location, operator experience and requirements, and the level of system complexity.

7.1.6 Monitoring

The monitoring/analytical costs for the implementation of the technology, which were tracked during the demonstration, amounted to $107,000. These costs are anticipated to be significantly higher than would be required for a typical similarly sized plant or as the plant is scaled-up for a number of reasons:

- The demonstration study that was conducted involved a number of scientific experiments to test the robustness of the technology. Hence, there was additional monitoring in frequency and the variety of analytes that would not be required under normal operation of any size FBR treatment system.
- In terms of monitoring, every National Pollutant Discharge Elimination System (NPDES) permit is unique with respect to the analytical requirements. Although an NPDES requirement is developed for the UV system at the MPITS, unique

monitoring analysis may be required based the technology choice and on the location of the plant.

7.2 Cost Drivers

The major anticipated cost drivers of the technology are the concentration of NDMA in the feed stream and the anticipated feed flow requiring treatment. Ultimately, this loading rate of NDMA dictates the HRT required by the FBR to maintain effective treatment to a low level effluent requirement. As the load increases, the required bed volume to treat the NDMA increases based on the maximum NDMA elimination capacity. The larger the HRT requirement, the greater the capital investment in the equipment is necessary. This requirement results in greater tank/vessel size, larger pumps, and more filter bed media. Typically, the full-scale FBR reactors are provided at a minimum of 3-foot diameter up to a maximum of a 14-foot diameter bed. If more bed volume is required, multiple 14-foot diameter beds are provided. The major limitation for the 14-foot diameter bed size is based on a transportation permit limitation. As the reactors increase in diameter, an economy-of-scale factor is observed in the design and fabrication requirements. However, this economy-of-scale savings can be offset by the increase of material costs. In addition to the capital investment required for the larger equipment, installation costs will increase as more manpower, larger installation equipment (cranes, rigs, etc.), larger diameter pipe and run lengths, and greater electrical equipment complexities are necessary.

Finally, with the larger HRT resulting from the greater NDMA loads, an increase in operating costs of chemical (oxygen, propane, and nutrients) and electrical consumption will occur. The cost of coal based electricity is a volatile market, so any increase in costs will have some impact on the overall operating costs of the FBR treatment system. Typical water treatment plants operate on a "Time of Use" basis where electricity costs are tiered based on peak demand. Hence, a plant will develop operating practices so that during the highest peak demand times (mid-day), the plant operates at significantly reduced capacity. Utilizing flow and contaminant concentration feed-forward control logic, the FBR drinking water system can be operated to minimize electrical consumption during peak demand. During peak times of the day (i.e., noon), the feed flow can be limited to the FBR. During non-peak times of the day, the full capacity of the plant can be utilized. The PLC is capable of adjusting the propane and oxygen addition accordingly to flow so that changes in feed flow do not affect treatment performance. Such effective control will minimize the electrical operating costs.

7.3 Cost Analysis

One of the reasons for selecting WSTF as the demonstration site was the existence of the MPITS with a UV treatment system for NDMA and a pre-treatment air stripper for VOCs. The technology cost analysis for this project compares the costs for the 125 gpm UV system at WSTF with an FBR system scaled to treat the same groundwater flow rate and load. The project assumptions are:

- 30 year remediation water project
- 125 gpm design treatment

- Existing extraction wells available
- NDMA feed concentration of 1 µg/L
- Temperature = 20^{o}C
- pH = 7.0-8.0 SU
- ORP > 100 mV
- Pre-treatment air stripper provided for both technologies

The life-cycle costs are estimated for the FBR water treatment production plant utilizing both the capital/investment and operating costs. The life-cycle costs are developed for the UV water treatment plant based on actual data provided by the operating facility (Zigmond, 2013). The assumptions are:

- Investment and operating costs based on 2013 dollars
- Well operation not included in costs
- Electrical energy costs at $0.062 kW/hr (averaged for peaking and non-peaking use) and $15.47/kW demand charge
- Amortized costs based on 30 years, 1.1 % real discount rate (OMB, 2013)
- FBR and UV Installation costs are comprised of the construction and engineering costs estimated based on US EPA Technology Design Panel Cost Model (EPA, 2000) as 1.5X the capital cost
- Oxygen generated on site using atmospheric air as source
- Propane at $2.32/gallon (Energy Information Administration, 2013)
- Nutrients of urea and DAP at $0.11/lb and $0.50/lb, respectively.
- UV polyphosphate addition, $10.91/gallon
- Labor technician at $100/hr (Routine labor assumed the same between FBR and UV)

The FBR treatment system (with oxygen generator) and the UV design, fabrication, installation, and operation costs are provided in Table 7.2.

Table 7.2 FBR and UV full-scale treatment system cost at 125 gpm and NDMA at 1 µg/L.

Parameter	UV	FBR	Notes
Capital and Installation			
Capital Costs	$317,000	$373,000	
Installation Costs (Engineering and Construction)	$475,500	$559,500	
Total Capital and Installation Costs	$792,000	$932,000	
Capital/Install Cost Amortization ($/yr)	$31,139	$36,643	30 yrs, 1.1% real discount rate
Total for 30 year Remediation	**$934,170**	**$1,099,300**	30 yrs, 1.1% real discount rate
Operating Costs			
Annual Chemical Addition			
Propane	NA	$1,263	6.31 lbs/day
Nutrient	NA	$300	DAP: 0.7 lbs/day, Urea: 2.3 lbs/day
Polyphosphate	$1,200	NA	110 gallons/yr
Total for 30 year Remediation	**$48,682**	**$63,408**	Includes 2% escalation/year
Electricity Consideration			
Electrical Demand (kW·hr/month)	11,470	3600	
Monthly Energy Cost	$659	$223	UV actual, FBR calculated
Monthly Demand Cost	$279	$74	UV 18 kW, FBR 5 kW
Total Monthly Cost	$938	$297	
Annual Cost	$11,256	$3,564	
Total for 30 year Remediation	**$456,634**	**$144,584**	Includes 2% escalation/year
Annual Equipment Replacement			
UV Lamp Replacement	$17,980	NA	$333/lamp changed out every 1.4 yrs, 12 hours labor
UV Quartz Sleeve Replacement	$1,976	NA	$115/sleeve changed out every 5 years, 16 hours labor
UV Lamp Ballast Replacement	$5,720	NA	$750/ballast changed out every 5 years, 16 hours labor
UV Wiper Insert Replacement	$1,160	NA	$10/wiper part, changed out every 2 years, 16 hours labor
FBR Media Replacement	NA	$500	2% loss per year
FBR Equipment Repair, Maintenance	NA	$5,000	O&M on pumps, valves, checking unit
Annual Cost	$26,836	$5,500	
Total for 30 year Remediation	**$1,088,685**	**$324,545**	Includes 2% escalation/year
Overall Costs			
Grand Total for 30 Year Remediation	**$2,528,171**	**$1,631,837**	

7.3.1 FBR System

The costs for a complete FBR treatment system to meet NDMA treatment requirements of reducing influent from 1 µg/L to below 4.2 ng/L are provided. Based on the WSTF water chemistry and associated HRT required, an FBR system to effectively treat 125 gpm of WSTF groundwater would need to be 5 feet in diameter with an expanded bed height of 20 feet (20% safety factor added). The plant would consist of one full-scale fluidized bed bioreactor,

constructed with welded, 304 stainless steel to API-650, including sidewall anchor chairs, closed top design and full stainless steel flat floor plate with access ladder, and a deck grating and handrail on roof. Included with the FBR is a fluidization pump, an influent distribution system, and effluent/biomass collection system, two biomass separators, 7100 pounds of carbon media (coconut shell based), and oxygen generator, and a gas delivery system (both oxygen and propane). Provided for the entire plant is a systems controls package that includes a NEMA 4 control panel, with system motor controls, Allen-Bradley SLC Series PLC with operator interface, and any required transformers or power supply. The total capital and installation costs for the FBR is estimated at $932,000 or $1,099,300 if amortized over 30 yrs at a 1.1% discount rate.

During the demonstration, the level of solids at the effluent was equal or less than provided at the feed. Based on this level of solids generated (< 10 mg/L TSS), additional equipment for solids removal is not provided. It is anticipated that the effluent of the FBR would be discharged to an infiltration pond. Any accumulation of solids would occur regardless of the technology implemented such that dredging and removal may be required.

For the implementation of such a treatment plant, the documentation for the project includes:

(1) Process description
(2) Process flow diagrams
(3) Material balance
(4) Piping and instrumentation diagrams
(5) Utility requirements
(6) Equipment and instrument cut sheets for ETI-supplied equipment/instruments
(7) General layout diagrams
(8) Detailed layouts for skidded equipment and vessels
(9) Electrical design drawings for the control panels
(10) Functional control specification and detailed process specification
(11) Equipment and instrument cut sheets
(12) Project schedule

The provided costs reflect all project administration, reporting, oversight of subcontracted services, preparation of O&M manuals and progress reports, installation supervision of major equipment, attendance at all project meetings, system mechanical shakedown and hydraulic testing, process startup, and initial operational training. In addition, an estimate of system installation costs that will be required at a particular site are also provided. These costs include both in-house and subcontractor work.

7.3.2 UV Treatment System

The existing technology at the site, the Mid-Plume Interception and Treatment System (MPITS), is a groundwater pump and treat facility designed for 125 gpm using UV technology (see Figures 4.1 – 4.3). Groundwater is pumped from five extraction wells (MPE-1, MPE-8, MPE-9, MPE-10, and MPE-11) at depths of ~ 320 ft below the surface to the treatment facility. This water is initially pumped into double-walled high-density polyethylene (HDPE) or double-walled

polyvinyl chloride (PVC) pipe that routes water to a surge tank in the treatment building. The surge tank enables a stable control volume of groundwater, so that flow going into an air stripper can be regulated. Before entering the surge tank, the groundwater is injected with a polyphosphate scale control chemical, which is distributed on a feed flow proportional basis. The chemical cleaning system is not currently being used since it is only implemented when the system is processing high turbidity water. From the surge tank, groundwater is then pumped into a 5-micron filter bank before entering the air stripper. The air stripper removes volatile organic compounds from the groundwater by passing ambient air from a blower upward through perforated trays as water flows downward through the trays. The volatilized VOCs from groundwater are discharged from the roof of building into the atmosphere. Effluent water from the air stripper is pumped into 1-micron filter banks before entering the TrojanUVPhox™ reactor . The groundwater is exposed to low pressure, amalgam ultraviolet light lamps. The UV light provided by the lamps destroys the NDMA via direct photolysis leading to dimethylamine, nitrate and nitrite (Stefan and Bolton, 2002). Treated groundwater exiting the UV reactor is then either recycled into a surge tank or proceeds to an infiltration basin. The MPITs has been running for over one year. The total capital and installation costs for the UV system is estimated at $792,000 or $942,170 if amortized over 30 yrs at a 1.1% discount rate.

7.3.3 Cost Comparison of FBR versus UV

The life-cycle costs for the UV and FBR systems were based on the capital equipment costs, the engineering and installation costs, and the overall operating costs of chemicals, electricity, and parts replacement. Difficulties arise in comparing any technology costs for applications where all costs are not accounted or estimates need to be developed. A few issues require addressing when comparing the data provided in Table 7.2:

- Both the FBR and UV system were quoted as continually operating systems at 125 gpm. However, downtime for both processes will differ. Hence, although remediation times were developed equally for both technologies over 30 years, these technologies may require actual different timelines to provide the same mass removal of NDMA.
- Quoted costs assumed wellhead pumping, the air stripper and associated infrastructure, a building and associated infrastructure, the infiltration pond construction and maintenance, and overall operation (labor, expenses) were assumed similar for both units. Hence, in order to provide as close a cost comparison for the FBR and the UV technology as possible, these costs were not included in the evaluation of either technology. Still, these costs could differ depending on the technology. For instance, the FBR may not require a building while the UV system would.

For these reasons, all of the costs provided in Table 7.2 must not be considered an absolute comparison. However, a general analysis of the costs can be undertaken:

- Capital costs for UV are lower compared to the FBR treatment system at the NDMA concentration treated.
- Installation/engineering costs for both technologies used scaling factors (EPA, 2000) that were a direct function of the capital cost. Hence, the UV installation/engineering cost by definition was less expensive than the FBR.
- Operating costs for chemicals favored the UV, but the difference over 30 years was not significant based on the overall treatment costs (less than $15,000)
- Operating costs for the electricity and the parts replacement favor the FBR significantly over the UV system. The UV electrical demand is 3X higher than the FBR, while the need for UV lamp replacement every 1.4 years makes up over half the 30-year remediation cost for UV parts. If the replacement frequency of the lamps increases over time, the overall costs will increase.
- Overall costs over the 30-year remediation project favor the FBR over the UV system by ~ $900,000.

The costs in Table 7.2 are only comparable for the specific site conditions quoted. However, some general cost sensitivity analysis based on flow and NDMA concentration has been

conducted to determine the applicability of the two technologies under different operating scenarios. In general, the trends are as follows:

- An increase in flow from 125 gpm up to 1000 gpm would result in a significant increase in both the UV and FBR capital costs to maintain adequate residence time to ensure NDMA treatment. The UV system would require more lamps to ensure sufficient exposure time to the NDMA is provided, with a linear increase versus flowrate in capital reflected in the number of additional lamps and quartz sleeves. The FBR would require a larger reactor so that the volume of biological active media was sufficient to react with the larger volume of water requiring treatment. The increase in the capital cost for the FBR system is not linear from 125 gpm to 1000 gpm, but instead is approximately 3X greater.
- An increase in flow from 125 gpm to 1000 gpm would require an increase in operating expenses for both systems. The operating costs of the UV would be expected to increase linearly with flow, with electrical demand per lamp being in proportion to the flow increase. The FBR would have an increase in oxygen in propane consumption on a linear rate with flow as well. However, lower dosing of the propane would be possible once an established biomass is created. This lower dosing requirement would minimize the impact of the cost increase of chemical addition with increasing flow.
- An increase in the NDMA concentration from 1 µg/L up to 5 µg/L would result in some level of capital cost increase with the UV system as longer residence times would be required for effective treatment of the NDMA. However, the amount of increase in capital expense would not be linearly proportional to the concentration as it is with flow. Concentration of NDMA entering the FBR was not varied during this pilot study. However, in prior bench-scale work, the residence time required to effectively treat up to 20 µg/L of NDMA was demonstrated to be 20-30 minutes, similar to that required to treat 1 µg/L in the field FBR. Such results indicate that a degree of robustness is afforded the FBR as the concentration of NDMA increases. Thus, an increase in FBR size is likely not required for moderate increases in NDMA influent concentrations (e.g., up to 20 µg/L).
- The electrical demand of a UV system follows a log-linear relationship. That is, to treat 1 µg/L to 1 ng/L (3 log order reduction) requires 3x the energy as treating 1 µg/L to 100 ng/L (1 log order reduction). Hence, as NDMA concentrations increase from 1 µg/L to 5 µg/L, or higher, electrical demand and O&M costs for the UV system will increase accordingly. For the FBR, bench-scale studies have demonstrated that an increase from 1 µg/L up to 20 µg/L of NDMA resulted in no increase in propane or oxygen consumption as the NDMA is treated cometabolically (i.e., cells are growing on propane not NDMA). Hence, unlike a UV system, the operating expenses for the FBR should not be affected by the increase in NDMA concentrations up to 20 µg/L.
- An increase in other factors, such as total suspended solids (TSS) in the groundwater, would not impact FBR costs as this type of biological system can effectively operate at TSS concentrations up to 100 mg/L. However, increasing TSS/turbidity would have a major detrimental effect on the ability of the UV lamps to provide sufficient energy to oxidize NDMA. Hence, a prefilter step may be required, raising capital and operating costs.

8.0 Implementation Issues

For this demonstration study, the implementation of the FBR treatment system to treat contaminated groundwater with NDMA has been shown to be possible and effective. Future implementation of the technology requires that the necessary permitting regulations are met, end user concerns are addressed, and lessons learned during the demonstration are implemented at the next scale.

8.1 Regulations

Under current practice, statewide regulatory agencies are provided primacy to implement regulations that meet the federally mandated Clean Water Act standards for discharges of treated water to the environment. This is achieved by these regulatory agencies through the implementation of an NPDES permit. However, the statewide regulatory agencies also have the latitude to institute specific additional limitations on an effluent discharge based upon sensitivity of the receiving body of land or water. For instance, if downstream of the effluent discharge point, there exists a drinking water aquifer, more stringent requirements may be enacted. In the event that regulations do not exist for a particular contaminant or a state determines that a more restrictive regulation is required, such authority to develop new or more stringent regulations based on a heath-based risk assessment or through other means is provided to each individual state by the federal government.

In terms of NDMA treatment, the Environmental Protection Agency lists NDMA on its Unregulated Contaminant Monitoring Regulation List 2 (UCMR 2; USEPA, 2007), while the New Mexico Environment Department (NMED) regulates the discharge of the NDMA in the effluent from NASA White Sands Test Facility (WSTF). Originally, WSTF was regulated at 10 ng/L of NDMA for discharge of treated groundwater for surface deposition for a number of years. After further review of the health risks associated with the contaminant, the NDMA concentration in their discharge limit was reduced from 10 ng/L to 4.2 ng/L. As additional health effects are realized for contaminants such as NDMA, additional future limitations may be placed on the effluent discharge requirements. Hence, as NDMA treatment is implemented throughout the country, technologies should continually be striving to treat to near non-detect levels (i.e., $\leq$ 2 ng/L) when possible.

In implementing a full-scale FBR treatment plant for WSTF, the NMED will require that an NPDES permit application be submitted and approved. This permit submittal will require a formal application and a technical report with sufficient information to demonstrate that the new treatment system can provide consistent, quality water meeting at least all of the requirements of the current NPDES permits for the discharge of NDMA treated water. Portions of this report generated for this demonstration study can be utilized to meet the requirements of the technical report submittal to the NMED. From such a submittal, the NMED will prepare an engineering evaluation report that will detail the water source, extent of contamination, contaminant migration, and effect on the receiving body of water. From this report, recommendations are developed for a permit that describe the treatment train, the specific operating regimes, and required monitoring program. Typical monitoring requirements may include 30-day average and maximum daily NDMA concentrations and general water chemistry parameters. However, because the specific FBR technology is a biological process, additional monitoring requirements may include such items as

total suspended solids, biochemical oxygen demand, chemical oxygen demand, total organic carbon, and heterotrophic plate count analyses.

Finally, additional permits that will be required in the implementation of the treatment technology will include a publicly owned treatment works discharge permit (if required for solids removal) and typical construction permits with the local municipalities.

8.2 End User Concerns
The primary end-users of this technology are expected to be industrial or military clients that have a history of NDMA usage or contamination at their facility. Additional stakeholders with interest in this FBR technology demonstration include the NMED, the EPA, and the DoD. The general concerns for all of the end users include: (1) technology performance; (2) technology cost; (3) ease of operation; (4) technology robustness; and the (5) effluent water quality. These issues, with guidance from WSTF, were effectively addressed and demonstrated throughout the study. The concerns are reflected in the performance objectives that are described in Sections 3.0 and 6.0.

Considerable process development has been implemented to ensure that the FBR treatment plant supplied a consistent supply of NDMA treated water. Using a sophisticated algorithm to adequately monitor and respond to process changes/requirements, the FBR treatment system has proven to be a robust, dependable treatment technology for NDMA treatment. The FBR treatment system technology is a custom built system and is not considered a commercially-off-the-shelf technology. However, numerous systems of varying size have been previously built and installed elsewhere treating more than 12 million gallons of oxyanions, chlorinated solvents, ethers, and alcohols to non-detect levels every day. Thus, the future procurement of an expanded system should not be considered problematic and a typical environmental/civil engineering firm will be able to scale-up and apply this technology in the field. The FBR treatment technology is not considered proprietary. However, specific components of the FBR are considered proprietary or are patented by ETI. These components include the FBR vessel distribution headers, the biomass removal system, and the control logic for the propane and oxygen addition by the PLC.

In implementing the full-scale FBR treatment system, a number of typical project issues will need to be addressed by those stakeholders involved in the implementation of this remediation process. These include:

- Land acquisition for the site of plant
- Site surveying and soil analysis
- Project civil, electrical, and mechanical engineering for plant fabrication/installation
- Preparation of sub-contractor bidding documents for fabrication/installation
- Project management and engineering during fabrication/installation
- Fabrication/installation labor, equipment, and materials
- Geotechnical engineering for production/reinjection well installation
- Preparation of well and water conveyance subcontractor bidding documents
- Drilling/installation of production and or reinjection wells (as necessary)
- Engineering design for water conveyance to/from the plant
- Water conveyance system (piping, booster pumps, labor, etc.)

- Discharge water permitting (NPDES)
- Other permitting required for installation and water conveyance
- Operation and maintenance of the plant

The implementation of such a "first-of-its-kind" technology to treat contaminated groundwater, rather than simply rely on energy intensive alternatives, to low-level water standards can serve as a new paradigm of water treatment for significantly impaired resources. With quality supplies of water rapidly declining throughout the United States, the implementation of such a biological treatment plant can be effectively used for NDMA contaminant removal.

8.3 Lessons Learned

Over the course of the demonstration project that entailed three months of design, two months of installation, and one year of operation, a number of lessons were learned in implementing the technology at a larger scale. Many of these issues are addressed in detail throughout prior sections of the report.

In summary, the design/equipment lessons include:

- It is critical to ensure that the fluidization pump can be primed correctly and that the pneumatically-operated slam valve function correctly at both the pilot- and the full-scale. This will prevent the possible back flow of water and GAC from the bottom of column into the media fluidization header and pipe. For the pilot-scale, a modification to the lower section of the reactor vessel such that the bottom header is more accessible is warranted.

- While the system is in recycle with the feed pump off, it was necessary to manually conduct any nutrient addition to the reactor. A means to add nutrient in either automatic or manual mode would minimize operator attention. This is typically available with the full-scale systems. Also, the chemical addition feed rates should be controllable at the PLC as opposed to only remotely at the pumps.

- The inclusion of a sensor to monitor when oxygen tank pressure is lower than fluidization pressure would prevent backflow of water from the T-107 bubbler into the oxygen line. A more robust check-valve system engineered into the gas delivery system would also prevent such a scenario.

- Adding a control program to the PLC that automatically adjusts the constants of oxygen and propane to maintain an operator set range for DO and LEL% would limit/minimize operator attention (and possible errors) during periods when the HRT requires adjustment.

- Installation of a water level sensor/indicator at the top of the reactor, located just below LEL sensor, would prevent the water level from rising too high. This did not occur during the demonstration, but there are scenarios where this is possible. An alarm could shut down the fluidization pump in the event the sensor was activated, preventing the water from rising to the LEL sensor height. Otherwise,

if the LEL sensor gets wet, it is required to be dried and recalibrated. This would limit downtime and prolong the life of the LEL sensor.

- Installation of an isolation manual valve after FCV-102 would allow maintenance to be performed on FCV-102 without the FBR reactor being emptied. This would minimize operator attention required.

- With regards to clearance height, the FBR is inherently a tall piece of treatment equipment (generally 10 to 26 ft tall). The biomass separator is difficult to remove for maintenance if the top of the FBR is near the roofline. If installed in a building, it is important to provide sufficient height beyond the top of the vessel to remove the biomass separator. Or, the biomass separator should be redesigned so it can be removed in sections at the top of the reactor.

- For all additives, the suction to the pumps should be at the base of the additive tank. Dual metering pumps for all chemical additives should be implemented to ensure that a stoppage of chemical additives does not occur.

- Manufacturer support of the on-line instrumentation is warranted as a preventive maintenance measure. Extended warranty and service contracts for such instrumentation that are critical to the operation of the plant (i.e., LEL meter) are recommended.

In summary, the operational/process lessons include:

- For an FBR HRT of 20 minutes (at 2.2 gpm for the pilot-scale), the propane and oxygen requirements were established at 35 mg/min (28.6 mg C/min) and 175 mg/min, respectively. This quantity of propane incorporated an excess beyond stoichiometric requirements to account for abiotic loss and microbial biomass incorporation. During steady-state operation, the oxygen and propane residuals in the FBR effluent averaged greater than 4 mg/L and ~ 30 µg/L, respectively. The feed of diammonium phosphate and urea can be adjusted to provide only minimal excess ammonia and orthophosphate in the FBR effluent during steady-state operation (< 1 mg/L each). Higher effluent concentrations may initially be required during FBR bed growth, but at equilibrium, low concentrations were maintained (~ 0.8 mg/L orthophosphate as P and < 0.2 mg/L ammonia as N).

- The interruption of forward feed flow or power to the plant is more detrimental to the system performance in the early stages of bed biofilm maturation. In general, plant interruptions should be kept at a minimum in the first sixty days of operation in order to maximize NDMA removal performance. The ability of the system to recover from such interruptions may be a function of the frequency and duration of such events. For shorter periods (days), the system was able to rebound within hours to days. Longer shutdown periods may have resulted in a different response in treatment.

- A rapid bed expansion did not occur during the study period. Although it was assumed that the full fluidized bed was utilized for biological treatment of the NDMA (at a 20 minute HRT), it may be possible that an even shorter HRT (10 minutes) could be utilized and still provide effective treatment. At an HRT of 10 minutes, effluent NDMA concentrations below 10 µg/L were consistently achieved. However, although values less than 4.2 µg/L were achievable, this level was not consistently met.

- Although the FBR was inoculated with a specific propanotroph (*Rhodococcus ruber* ENV425), that organism was not among the most dominant bacteria in the FBR by Day 249 of FBR operation. Rather, various *Mycobacterium* spp., among which are many different propanotrophs, dominated the FBR based on molecular analysis. Presumably, these native propanotrophs seeded the reactor from WSTF groundwater. Clearly, these propanotrophs were capable of degrading NDMA to low concentrations, which is consistent with our previous findings that this ability is widespread among propanotrophic bacteria. These data bring into question the necessity of inoculating an FBR with a specific microbe for NDMA treatment if the feed water contains indigenous propanotrophs. However, given that it is relatively inexpensive to inoculate a reactor, and that propanotrophs are not indigenous in all environments, seeding an FBR with ENV425 or a similar propanotrophic culture is recommended.

- The grade of propane and oxygen were not laboratory quality, but instead an industrial quality with a lower level of purity. The presence of contamination in the gases provided did not appear to have a harmful effect on the microbes present. This is important as industrial grade propane is less expensive and more readily available. The oxygen can be generated on site using atmospheric air as the source gas.

- The presence of chlorinated solvents and Freon did not significantly hinder the performance of the FBR when introduced. This experiment was conducted for a short period of time, but no/minimal short-term negative effects were observed. Hence, if certain contaminants are not required to be treated per the NPDES permit and an FBR is to be implemented for NDMA treatment, the elimination of the upstream air stripper may be possible. However, long-term tests of FBR operation in the presence of the co-contaminants should be conducted, and potential increases in the co-contaminants should be considered, as increasing concentrations could have a detrimental effect on NDMA treatment.

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APPENDICES

Appendix A: Points of Contact

POINT OF CONTACT Name	ORGANIZATION Name Address	Phone Fax E-mail	Role in Project
Paul B. Hatzinger, PhD	Shaw Environmental Inc. 17 Princess Road Lawrenceville, NJ 08648	(609) 895-5356 (office) (267) 337-4003 (cell) (609) 895-1858 (fax) Paul.hatzinger@cbifederalservices.com	Co-PI (Lab and Field Studies)
Todd S. Webster, PE, PhD	Envirogen Technologies, Inc. 10400 Trademark St. Rancho Cucamonga, 91730	(619) 286-2587 (office) (619) 887-1385 (cell) (619) 286-2587 (fax) twebster@envirogen.com	Co-PI (Engineering and Field Studies)
Celeste Lewis	Envirogen Technologies, Inc. 10400 Trademark St. Rancho Cucamonga, 91730	(877) 312-8950 (office) (727) 457-4159 (cell) clewis@envirogen.com	Field Engineer
Sam Wong	Envirogen Technologies, Inc. 10400 Trademark St. Rancho Cucamonga, 91730	(877)312-8950 (office) (626)497-5076 (cell) swong@envirogen.com	Senior Process Engineer
Michael Zigmond	NASA-JSC White Sands Test Facility P.O. Box 20 Las Cruces, NM 88012	(575) 524-5484 (office) (575) 527-6731 (fax) (575) 640-6661 (cell) Michael.J.Zigmond@nasa.gov	NASA Remediation Project Manager

Appendix B: Analytical Results and FBR Operational Data

Appendix B: NDMA and DMN DATA

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA and DMN in the FBR									QA/QC (WECK)				
Date	Time	Elapsed Time	NDMA Influent Method 607	NDMA Effluent Method 607	NDMA Effluent HRMS	DMN Influent	DMN Effluent	DMN Effluent HRMS	NDMA Method 521 (1Lbottle no thiosulfate)	NDMA Method 521 (2 500mL bottles with thiosulfate)	NDMA Method 521 (2 500mL bottles no thiosulfate)	NDMA Method 521 (2 500mL bottles with thiosulfate) Field Blank	NDMA Method 521 (2 500mL bottles no thiosulfate) Field Blank
d/m/y	hh:mm	Days	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
14-Mar-12	8:28	6	0.91	0.92		0.48	0.500						
4-Apr-12	8:00	27	1.24	0.99		0.65	0.560						
10-Apr-12	9:15	33	1.07	0.98		0.56	0.570						
23-May-12	12:30	76	1.18	1.07		0.63	0.640						
29-May-12	12:50	82	1.36	1.13		0.72	0.630						
7-Jun-12	10:40	91	1.26	0.11		0.64	0.060						
11-Jun-12	7:50	95	1.15	0.06		0.6	0.040						
13-Jun-12	8:00	97	1.14	0.020		0.59	0.020						
18-Jun-12	11:00	102	1.16	0.020		0.61	0.010						
20-Jun-12	10:00	104	0.97	0.011		0.53	0.009						
25-Jun-12	12:00	109	1.11	0.009		0.59	0.008						
27-Jun-12	9:00	111	0.93	0.008		0.48	0.010						
3-Jul-12	8:45	117	1.19	0.020		0.63	0.020						
5-Jul-12	9:30	119	0.91	0.020		0.48	0.020						
7-Jul-12	17:45	121	1.30	0.020		0.69	0.020						
11-Jul-12	10:40	125	0.80	0.008		0.42	0.010						
16-Jul-12	12:00	130	1.06	0.005		0.55	0.006						
30-Jul-12	9:35	144	0.49	0.010	0.024	0.26	0.005						
1-Aug-12	11:40	146	1.48	0.008	0.024	0.77	0.008						
6-Aug-12	11:20	151	1.05	0.010	0.013	0.55	0.010						
8-Aug-12	8:10	153	2.61	0.010	0.018	1.4	0.005						
13-Aug-12	8:15	158	1.10	0.010	0.003	0.58	0.009						
16-Aug-12	12:00	161	1.26	0.010	0.005	0.65	0.006						
20-Aug-12	10:45	165	1.46	0.010	0.005	0.76	0.010						

MDL: DMN = 0.010 ug/L

MDL: NDMA EPA 607 = 0.010 ug/L

Appendix B: NDMA and DMN DATA

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA and DMN in the FBR									QA/QC (WECK)				
Date	Time	Elapsed Time	NDMA Influent Method 607	NDMA Effluent Method 607	NDMA Effluent HRMS	DMN Influent	DMN Effluent	DMN Effluent HRMS	NDMA Method 521 (1Lbottle no thiosulfate)	NDMA Method 521 (2 500mL bottles with thiosulfate)	NDMA Method 521 (2 500mL bottles no thiosulfate)	NDMA Method 521 (2 500mL bottles with thiosulfate) Field Blank	NDMA Method 521 (2 500mL bottles no thiosulfate) Field Blank
d/m/y	hh:mm	Days	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
20-Aug-12	10:45	165	1.46	0.010	0.0049	0.76	0.009						
22-Aug-12	11:00	167	0.78	0.010	0.0025	0.42	0.010						
27-Aug-12	11:15	172	1.39	0.010	0.0032	0.73	0.010						
30-Aug-12	7:50	175	1.05	0.010	0.0042	0.55	0.010						
5-Sep-12	12:45	181	0.87	0.010	0.0031	0.46	0.010						
6-Sep-12	8:05	182	1.08	0.010	0.0034	0.56	0.010						
10-Sep-12	11:00	186	1.11	0.010	0.0036	0.60	0.010						
12-Sep-12	10:30	188	1.10	0.010	0.0035	0.59	0.010						
20-Sep-12	9:35	196	1.24	0.010	0.0042	0.65	0.010						
24-Sep-12	11:00	200	1.32	0.010	0.0031	0.71	0.010						
26-Sep-12	10:30	202	1.18	0.010	0.0023	0.62	0.010						
2-Oct-12	10:35	208	0.85	0.010	0.0031	0.46	0.010						
4-Oct-12	9:30	210	0.81	0.010	0.0031	0.44	0.010						
10-Oct-12	11:45	216	0.74	0.010	0.0024	0.4	0.010						
11-Oct-12	12:00	217	0.03	0.010	0.0011	0.02	0.010						
15-Oct-12	12:00	221	0.97	0.010	0.0030	0.54	0.010						
17-Oct-12	11:00	223	0.85	0.010	0.0027	0.45	0.010						
22-Oct-12	10:10	228	0.01	0.010	0.0010	0.009	0.010						
24-Oct-12	12:00	230	1.25	0.010	0.0018	0.65	0.010						
29-Oct-12	11:00	235	0.86	0.008	0.0022	0.45	0.010						
31-Oct-12	8:35	237	0.81	0.006	0.0028	0.42	0.010						
5-Nov-12	10:15	242	0.65	0.008	0.0038	0.36	0.010						
7-Nov-12	9:00	244	0.91	0.007	0.0037	0.51	0.010		0.0023	0.025			
7-Nov-12	2:00	244	1.14		0.0032	0.63							

MDL: DMN = 0.010 ug/L

MDL: NDMA EPA 607 = 0.010 ug/L

Appendix B: NDMA and DMN DATA

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA and DMN in the FBR									QA/QC (WECK)				
Date	Time	Elapsed Time	NDMA Influent Method 607	NDMA Effluent Method 607	NDMA Effluent HRMS	DMN Influent	DMN Effluent	DMN Effluent HRMS	NDMA Method 521 (1Lbottle no thiosulfate)	NDMA Method 521 (2 500mL bottles with thiosulfate)	NDMA Method 521 (2 500mL bottles no thiosulfate)	NDMA Method 521 (2 500mL bottles with thiosulfate Field Blank	NDMA Method 521 (2 500mL bottles no thiosulfate) Field Blank
d/m/y	hh:mm	Days	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
12-Nov-12	8:00	249	0.82	0.010	0.0028	0.46	0.010						
14-Nov-12	10:45	251	0.78	0.010	0.0049	0.43	0.010						
19-Nov-12	10:40	256	0.66	0.010	0.0041	0.39	0.010						
26-Nov-12	9:30	263	0.71	0.010	0.0041	0.4	0.010						
28-Nov-12	10:15	265	1.17	0.010	0.0083	0.61	0.010						
3-Dec-12	12:30	270	0.80	0.010	0.0068	0.43	0.010						
5-Dec-12	11:00	272	0.71	0.010	0.0102	0.39	0.010						
10-Dec-12	11:00	277	0.89	0.010	0.0081	0.48	0.010	0.0241					
12-Dec-12	10:30	279	0.84	0.010	0.0088	0.45	0.010	0.0456					
17-Dec-12	12:25	284	0.73	0.009	0.0059	0.39	0.010	0.0356	0.0036	0.035		0.024	ND
19-Dec-12	9:20	286	0.73	0.010	0.0036	0.4	0.010	0.0473					
22-Jan-13	7:00	320	1.46	0.010	0.0079	0.78	0.010	0.0023					
24-Jan-13	11:00	322	1.09	0.006	0.0075	0.58	0.010	0.0024					
28-Jan-13	10:15	326	1.18	0.007	0.0046	0.63	0.010	0.0014					
30-Jan-13	10:30	328	1.07	0.010	0.0056	0.57	0.010	0.002					
4-Feb-13	9:10	333	0.84	0.001	0.0048	0.44	0.010	0.0009					
7-Feb-13	7:50	336	1.11	0.010	0.0051	0.55	0.010	0.0008					
11-Feb-13	7:55	257	1.06	0.010	0.0040	0.51	0.010	0.001					
28-Feb-13	10:00	357	0.74	0.010	0.0097	0.43	0.006	0.0035					
4-Mar-13	11:30	361	1.02	0.010	0.0142	0.58	0.006	0.0049					
6-Mar-13	7:40	363	0.91	0.010	0.0073	0.52	0.010	0.0024					
13-Mar-13	1:15	370	1.04	0.010	0.0078	0.6	0.010	0.0027	0.004	0.0027	0.0031	ND	ND
14-Mar-13	9:52	371	0.99	0.010	0.0065	0.57	0.010	0.0019					

MDL: DMN = 0.010 ug/L

MDL: NDMA EPA 607 = 0.010 ug/L

Appendix B: NDMA and DMN DATA

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA and DMN in the FBR									QA/QC (WECK)				
Date	Time	Elapsed Time	NDMA Influent Method 607	NDMA Effluent Method 607	NDMA Effluent HRMS	DMN Influent	DMN Effluent	DMN Effluent HRMS	NDMA Method 521 (1Lbottle no thiosulfate)	NDMA Method 521 (2 500mL bottles with thiosulfate)	NDMA Method 521 (2 500mL bottles no thiosulfate)	NDMA Method 521 (2 500mL bottles with thiosulfate) Field Blank	NDMA Method 521 (2 500mL bottles no thiosulfate) Field Blank
d/m/y	hh:mm	Days	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
18-Mar-13	9:45	375	0.73	0.010	0.0055	0.43	0.010	0.0019					
20-Mar-13	6:30	377	0.81	0.011	0.0053	0.48	0.010	0.0015					

MDL: DMN = 0.010 ug/L

MDL: NDMA EPA 607 = 0.010 ug/L

Appendix B: NDMA and DMN DATA

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA and DMN in the FBR														QA/QC (SWRI)
Date	Time	Elapsed Time	Duplicate NDMA influent	Duplicate Nitrodimethylamine Influent	Duplicate NDMA HRMS Effluent	Split -1 NDMA HRMS Effluent	Split -2 NDMA Low level Effluent	Trip blank HRMS NDMA	Field Blank Influent NDMA	Field Blank Effluent DMN	NDMA Effluent at V-149	DMN Effluent at V-149	Duplicate NDMA influent filtered	Duplicate DMN Influent filtered
d/m/y	hh:mm	Days	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
17-Oct-12	11:00	140	0.84	0.44				0.00308						
24-Oct-12	12:00	147			0.00342	0.00179	0.0041		0.01	0.01	0.01	0.01		
19-Nov-12	10:40	173	0.74	0.43									0.69	0.4

MDL: DMN = 0.010 ug/L

MDL: NDMA EPA 607 = 0.010 ug/L

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR												
Date	Time	Elapsed Time	Feed Flow FIT-101	System Feed Pressure PI-101	P-101 Discharge Pressure PI-102	Fluidization Flow FIT-102	FBR Influent Pump Discharge Pressure PI-103	System pH AIT-105	System Temperature AIT-105	Effluent D.O. AIT-103	Effluent Temperature AIT-103	FBR Fludization Pressure PI-104
d/m/y	hh: mm	Days	gpm	psig	psig	gpm	psig	pH unit	°C	mg/l	°C	psig
8-Mar-12	9:02	0	3.0	3.0	11.0	9.7	24.0	7.8	24.4	3.1	24.5	5.0
12-Mar-12	8:27	4	3.0	3.0	11.5	9.7	24.0	8.3	23.6	5.9	23.6	5.0
12-Mar-12	11:00	4	3.2	2.5	11.3	9.7	24.0	8.4	24.3	5.7	24.3	5.0
14-Mar-12	8:28	6	3.3	2.0	10.5	9.7	24.0	8.4	23.8	5.9	23.8	5.0
16-Mar-12	9:30	8	3.2	1.5	10.5	9.7	24.0	8.4	24.0	5.9	24.0	5.0
19-Mar-12	10:00	11	3.1	1.5	10.3	9.7	24.0	8.2	23.7	5.8	23.7	5.0
21-Mar-12	8:05	13	3.2	2.0	11.0	9.7	24.0	8.3	22.9	6.1	22.8	5.0
23-Mar-12	12:00	15	3.1	1.5	10.0	9.7	24.0	8.3	24.3	5.7	24.3	5.0
26-Mar-12	15:30	18	3.1	1.0	10.0	9.7	24.0	8.2	24.7	5.5	24.8	5.0
27-Mar-12	8:00	19	3.6	4.0	13.0	9.7	24.0	8.3	24.0	5.8	23.9	5.0
27-Mar-12	11:33	19	3.3	2.0	10.5	9.7	24.0	8.5	24.3	5.3	24.3	5.0
30-Mar-12	12:45	22	3.2	4.0	13.0	9.7	24.0	8.4	24.4	5.6	24.4	5.0
2-Apr-12	16:00	25	3.0	3.0	11.5	9.7	24.0	8.3	24.1	5.5	24.1	5.0
4-Apr-12	8:00	27	2.8	2.0	11.0	9.7	24.0	8.2	23.8	5.6	23.8	4.5
5-Apr-12	9:30	28	3.0	2.5	11.0	9.7	24.0	8.2	24.3	5.5	24.3	5.0
10-Apr-12	9:15	33	3.0	1.5	10.5	9.7	24.0	8.3	25.2	5.1	25.3	5.0
16-Apr-12	13:30	39	3.1	3.0	12.0	9.7	24.0	8.1	24.1	2.8	24.1	5.0
18-Apr-12	12:30	41	3.1	2.5	11.5	9.7	24.0	8.3	24.8	5.3	24.9	5.0
19-Apr-12	10:30	42	2.9	1.5	11.0	9.7	24.0	8.3	24.4	5.2	24.5	5.0
24-Apr-12	9:08	47	OFF	0.0	0.0	9.6	24.0	6.8	33.3	2.0	33.2	5.0
26-Apr-12	12:00	49	OFF	0.0	0.0	9.6	24.0	6.6	33.5	2.0	33.4	4.5
30-Apr-12	10:15	53	OFF	0.0	0.0	9.6	24.0	6.4	33.0	2.1	32.8	4.5
30-Apr-12	14:00	53	3.3	0.0	9.0	9.7	24.0	7.9	27.2	2.9	27.8	5.0
30-Apr-12	15:00	53	3.2	0.0	9.0	9.7	24.0	8.1	26.0	3.9	26.2	5.0

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR												
Date	**Time**	**Elapsed Time**	**Feed Flow FIT-101**	**System Feed Pressure PI-101**	**P-101 Discharge Pressure PI-102**	**Fluidization Flow FIT-102**	**FBR Influent Pump Discharge Pressure PI-103**	**System pH AIT-105**	**System Temperature AIT-105**	**Effluent D.O. AIT-103**	**Effluent Temperature AIT-103**	**FBR Fludization Pressure PI-104**
d/m/y	**hh: mm**	**Days**	**gpm**	**psig**	**psig**	**gpm**	**psig**	**pH unit**	**^{o}C**	**mg/l**	**^{o}C**	**psig**
1-May-12	15:30	54	3.0	0.0	9.0	9.7	24.0	8.3	25.5	4.4	25.6	5.0
3-May-12	11:15	56	3.2	2.5	11.5	9.7	24.0	8.3	24.9	3.7	25.0	5.0
3-May-12	12:00	56	3.1	2.0	11.0	9.7	24.0	8.3	25.0	4.0	25.0	5.0
3-May-12	13:30	56	3.4	3.5	12.5	9.7	24.0	8.4	25.2	4.4	25.3	5.0
7-May-12	11:15	60	OFF	0.0	0.0	9.5	23.0	8.2	25.5	3.5	25.4	5.0
10-May-12	16:45	63	OFF	0.0	0.0	9.6	23.5	7.3	23.7	1.4	23.8	5.0
14-May-12	8:15	67	OFF	0.0	0.0	9.5	22.0	7.3	32.1	1.9	32.0	5.0
14-May-12	12:15	67	3.8	6.0	15.0	9.6	24.0	8.1	25.6	3.4	25.9	5.0
15-May-12	15:00	68	OFF	0.0	0.0	9.7	22.0	7.9	26.7	2.4	26.8	5.0
21-May-12	14:15	74	3.3	1.0	10.0	9.7	24.0	8.0	25.7	7.7	26.0	5.0
22-May-12	16:00	75	3.4	1.5	11.0	9.7	24.0	8.2	25.5	4.0	25.9	4.5
23-May-12	12:30	76	3.2	0.0	9.0	9.8	24.0	8.2	25.3	4.2	25.5	5.0
25-May-12	12:00	78	3.3	1.5	10.5	9.7	24.0	8.3	25.2	4.4	25.2	5.0
29-May-12	12:50	82	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
30-May-12	13:05	83	OFF	0	0.0	9.7	23.50	7.6	31.7	2.0	31.0	4.5
30-May-12	14:50	83	OFF	0	0.0	9.6	24.00	7.4	31.1	5.5	31.0	4.5
30-May-12	16:08	83	OFF	0	0.0	9.7	24.00	7.5	31.6	4.4	31.6	4.2
31-May-12	8:00	84	OFF	0	0.0	9.8	24.00	7.4	32.4	4.0	32.3	5.0
31-May-12	9:15	84	OFF	0	0.0	9.8	24.00	7.5	32.2	4.1	32.1	5.0
31-May-12	10:30	84	OFF	0	0.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
31-May-12	11:45	84	OFF	0	0.0	9.7	24.00	7.5	32.6	3.3	32.5	5.0
31-May-12	14:00	84	OFF	0	0.0	9.8	24.00	7.5	33.1	3.3	33.0	5.0
31-May-12	14:30	84	OFF	0	0.0	9.7	24.00	7.4	33.3	3.4	33.2	4.5
1-Jun-12	7:15	85	OFF	0	0.0	9.6	24.00	7.4	33.1	3.6	32.9	5.0

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR												
Date	Time	Elapsed Time	Feed Flow FIT-101	System Feed Pressure PI-101	P-101 Discharge Pressure PI-102	Fluidization Flow FIT-102	FBR Influent Pump Discharge Pressure PI-103	System pH AIT-105	System Temperature AIT-105	Effluent D.O. AIT-103	Effluent Temperature AIT-103	FBR Fludization Pressure PI-104
d/m/y	hh:mm	Days	gpm	psig	psig	gpm	psig	pH unit	^{o}C	mg/l	^{o}C	psig
1-Jun-12	10:00	85	OFF	0	0.0	9.8	24.00	7.5	33.0	3.7	32.9	5.0
1-Jun-12	12:00	85	OFF	0	0.0	9.8	24.00	7.5	33.4	3.7	33.3	5.0
2-Jun-12	9:00	86	OFF	0	0.0	9.7	24.00	7.3	33.0	3.6	32.8	5.0
2-Jun-12	10:30	86	OFF	0	0.0	9.7	24.00	7.4	33.1	3.7	33.0	5.0
2-Jun-12	11:30	86	OFF	0	0.0	9.8	24.00	7.4	34.5	3.7	34.4	5.0
2-Jun-12	12:30	86	Off	0	0.0	9.8	24.00	7.5	32.3	5.1	31.9	5.0
4-Jun-12	8:30	88	Off	0	0.0	9.8	24.00	7.2	33.0	3.6	32.9	5.0
4-Jun-12	13:30	88	Off	0	0.0	9.8	24.00	7.2	33.5	3.6	33.6	5.0
5-Jun-12	14:30	89	Off	0	0.0	9.8	24.00	7.4	31,8	4.3	31.7	5.0
6-Jun-12	9:00	90	Off	0	0.0	9.7	24.00	7.2	32.7	3.5	32.6	5.0
6-Jun-12	13:07	90	0.69	3.5	13.0	9.8	24.00	7.2	31.6	9.8	31.9	4.5
6-Jun-12	15:40	90	0.70	4.0	14.0	9.7	24.00	7.3	30.1	8.6	30.3	4.5
7-Jun-12	8:05	91	0.72	4.5	13.5	9.7	24.00	7.4	26.7	8.7	26.7	5.0
7-Jun-12	10:40	91	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
7-Jun-12	12:00	91	0.75	5.0	14.5	9.7	24.00	7.5	27.3	6.4	27.4	5.0
7-Jun-12	13:20	91	0.68	3.0	13.5	9.7	24.00	7.5	27.6	7.0	27.7	4.5
8-Jun-12	8:00	92	0.68	4.5	13.5	9.7	24.00	7.4	26.6	7.6	26.7	5.0
8-Jun-12	10:30	92	0.65	3.0	13.0	9.7	24.00	7.4	21.1	7.5	27.1	5.0
8-Jun-12	12:15	92	0.65	3.0	13.0	9.7	24.00	7.5	27.5	7.4	27.6	5.0
8-Jun-12	13:00	92	0.67	4.5	13.5	9.8	24.00	7.5	27.8	7.3	27.9	5.0
8-Jun-12	14:00	92	0.69	4.5	13.5	9.8	24.00	7.5	28.0	7.1	28.1	5.0
9-Jun-12	10:40	93	0.71	3.5	13.0	9.7	24.00	7.4	27.2	7.0	27.2	5.0
9-Jun-12	12:00	93	0.75	3.0	12.5	9.7	24.00	7.4	27.4	7.7	27.4	5.0

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR												
Date	Time	Elapsed Time	Feed Flow FIT-101	System Feed Pressure PI-101	P-101 Discharge Pressure PI-102	Fluidization Flow FIT-102	FBR Influent Pump Discharge Pressure PI-103	System pH AIT-105	System Temperature AIT-105	Effluent D.O. AIT-103	Effluent Temperature AIT-103	FBR Fludization Pressure PI-104
d/m/y	hh: mm	Days	gpm	psig	psig	gpm	psig	pH unit	°C	mg/l	°C	psig
9-Jun-12	13:00	93	0.71	4.0	13.5	9.7	24.00	7.4	27.6	7.4	27.7	5.0
9-Jun-12	14:00	93	0.73	3.0	14.0	9.8	24.00	7.4	27.8	7.4	27.9	5.0
9-Jun-12	15:00	93	0.74	4.5	14.0	9.8	24.00	7.4	27.9	8.0	28.0	5.0
11-Jun-12	7:50	95	0.67	4.0	13.0	9.7	24.00	7.2	26.7	7.5	26.7	5.0
11-Jun-12	11:30	95	0.67	4.0	13.0	9.7	24.00	7.3	27.4	8.2	27.4	5.0
11-Jun-12	13:00	95	0.68	4.0	13.0	9.7	24.00	7.3	27.9	8.2	27.9	5.0
11-Jun-12	14:00	95	0.69	4.0	13.6	9.7	24.00	7.4	28.1	8.6	28.2	5.0
13-Jun-12	8:00	97	0.67	5.0	14.0	9.6	23.50	7.0	27.0	8.2	26.9	5.0
13-Jun-12	13:40	97	0.64	3.5	13.0	9.7	23.50	7.2	28.2	8.4	28.3	5.0
13-Jun-12	15:00	97	0.68	4.00	14.0	9.7	24.00	7.4	28.4	8.1	28.5	5.0
14-Jun-12	8:30	98	0.72	4.00	13.5	9.6	23.00	7.0	27.0	8.7	26.9	5.0
14-Jun-12	9:00	98	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
14-Jun-12	11:00	98	0.73	4.00	13.5	9.7	23.50	7.1	27.3	8.7	27.3	5.0
15-Jun-12	8:00	99	0.75	5.00	14.0	9.6	23.00	7.0	27.0	9.3	27.0	5.o
15-Jun-12	12:15	99	0.73	5.00	14.0	9.6	23.00	7.1	27.8	7.8	27.9	5.0
16-Jun-12	22:00	100	0.73	4.00	12.5	9.62	22.00	7.3	29.5	5.3	29.5	5.0
18-Jun-12	11:00	102	0.76	4.50	14.0	9.55	22.00	7.0	28.0	7.2	28.1	5.0
20-Jun-12	10:00	104	0.64	3.00	12.5	9.30	21.00	7.0	27.1	7.9	27.1	5.0
20-Jun-12	12:20	104	0.75	4.00	13.0	9.41	22.00	7.1	27.5	7.7	27.6	5.0
22-Jun-12	9:00	106	0.67	4.00	13.0	9.40	21.00	7.0	27.8	7.3	27.9	5.0
25-Jun-12	12:00	109	0.77	4.50	14.0	9.35	21.00	6.8	28.3	7.4	28.5	5.0
27-Jun-12	9:00	111	0.75	5.00	14.0	9.26	20.00	6.9	27.5	7.3	27.6	5.0
27-Jun-12	12:30	111	0.70	2.50	12.5	9.45	20.00	7.3	28.3	6.7	28.4	5.0
28-Jun-12	10:25	112	1.01	5.00	14.0	9.61	20.00	7.1	27.8	8.1	28.0	5.0

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR												
Date	Time	Elapsed Time	Feed Flow FIT-101	System Feed Pressure PI-101	P-101 Discharge Pressure PI-102	Fluidization Flow FIT-102	FBR Influent Pump Discharge Pressure PI-103	System pH AIT-105	System Temperature AIT-105	Effluent D.O. AIT-103	Effluent Temperature AIT-103	FBR Fludization Pressure PI-104
d/m/y	hh:mm	Days	gpm	psig	psig	gpm	psig	pH unit	°C	mg/l	°C	psig
2-Jul-12	11:15	116	1.04	5.50	15.0	9.38	20.00	7.3	27.3	4.0	27.3	5.0
3-Jul-12	8:45	117	0.98	4.50	13.5	9.31	20.00	7.4	27.5	8.0	27.6	5.0
5-Jul-12	9:30	119	1.03	4.50	13.5	9.18	20.00	7.3	27.0	8.2	27.0	6.0
7-Jul-12	17:45	121	1.02	3.00	12.0	9.75	20.00	7.4	28.8	4.4	29.0	6.0
9-Jul-12	12:15	123	1.05	3.00	12.5	9.63	20.00	7.4	27.4	8.1	27.6	5.5
11-Jul-12	10:40	125	1.05	4.00	13.0	9.64	19.50	7.2	27.5	7.3	27.6	5.5
12-Jul-12	8:15	126	1.04	6.00	15.0	9.52	19.50	6.8	26.8	7.5	27.8	6.0
12-Jul-12	11:45	126	1.03	3.50	13.0	9.55	19.50	7.1	27.3	6.8	27.5	5.5
16-Jul-12	12:00	130	1.00	3.00	12.5	9.18	18.50	6.8	27.5	6.7	27.7	7.0
19-Jul-12	17:00	133	1.08	6.00	15.0	9.61	54.00	7.7	28.5	20.0	29.0	8.0
20-Jul-12	11:15	134	1.02	4.50	13.5	9.75	54.00	7.7	27.7	7.2	28.0	8.0
23-Jul-12	11:45	137	OFF	0.00	0.0	9.73	54.00	7.6	29.4	7.0	29.5	8.0
24-Jul-12	20:45	138	1.05	5.50	15.0	9.77	24.50	7.3	28.5	4.4	28.8	8.0
25-Jul-12	12:15	139	OFF	0.00	0.0	9.67	24.50	7.4	27.8	5.4	27.9	8.0
25-Jul-12	13:40	139	OFF	0.00	0.0	9.66	24.20	7.3	28.1	5.1	28.3	8.0
26-Jul-12	13:00	140	OFF	0.00	0.0	9.64	24.00	7.3	28.2	6.1	28.6	7.5
26-Jul-12	15:00	140	1.02	9.00	18.0	9.81	24.20	7.4	27.8	7.5	28.3	7.5
27-Jul-12	11:15	141	1.04	7.50	17.0	9.65	24.50	7.5	26.8	6.5	27.1	7.5
30-Jul-12	9:35	144	1.01	4.00	13.5	9.71	24.50	7.5	26.4	7.1	26.6	8.0
1-Aug-12	11:40	146	1.02	3.00	12.5	9.77	24.50	7.5	26.5	6.3	26.7	7.5
3-Aug-12	10:45	148	1.06	4.50	14.0	9.74	24.50	7.5	26.5	6.4	26.7	7.5
6-Aug-12	11:20	151	1.10	4.50	13.5	9.65	24.50	7.3	27.0	7.3	27.2	7.5
8-Aug-12	8:10	153	1.02	3.50	12.5	9.65	24.00	7.1	26.9	7.6	27.8	8.0
8-Aug-12	14:20	153	OFF	0.00	0.0	9.68	24.00	7.3	28.5	5.8	28.6	7.8

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR													
Date	Time	Elapsed Time	Feed Flow FIT-101	System Feed Pressure PI-101	P-101 Discharge Pressure PI-102	Fluidization Flow FIT-102	FBR Influent Pump Discharge Pressure PI-103	System pH AIT-105	System Temperature AIT-105	Effluent D.O. AIT-103	Effluent Temperature AIT-103	FBR Fludization Pressure PI-104
d/m/y	hh:mm	Days	gpm	psig	psig	gpm	psig	pH unit	^{o}C	mg/l	^{o}C	psig
9-Aug-12	13:30	154	1.00	4.00	13.5	9.72	24.00	6.9	28.9	5.1	29.2	7.5
13-Aug-12	8:15	158	1.05	3.50	13.5	9.77	24.50	7.0	26.7	6.9	26.8	8.0
13-Aug-12	12:10	158	1.10	4.00	13.0	9.69	24.50	7.2	26.8	6.9	27.0	8.0
15-Aug-12	8:21	160	OFF	0.00	0.0	9.62	24.00	7.1	27.2	6.1	27.2	7.0
15-Aug-12	11:00	160	1.07	7.00	17.0	9.7	24.00	7.5	27.3	6.2	27.5	7.5
16-Aug-12	12:00	161	1.10	4.00	13.5	9.7	24.00	7.5	26.9	7.0	27.1	7.5
20-Aug-12	10:45	165	1.05	3	12.0	9.6	24.00	7.2	26.8	5.7	27.0	7.5
20-Aug-12	13:00	165	1.45	5	14.5	9.7	24.00	7.3	26.9	6.5	27.1	7.5
22-Aug-12	11:00	167	1.45	4.50	14.0	9.7	24.00	7.2	26.6	6.7	26.7	7.5
23-Aug-12	11:30	168	OFF	0.00	0.0	9.6	24.00	7.6	28.3	5.0	28.4	7.5
23-Aug-12	17:00	168	1.40	4.00	13.0	9.7	24.00	7.6	27.8	6.2	28.0	7.5
24-Aug-12	10:05	169	OFF	0.00	0.0	9.6	23.50	7.3	29.4	5.0	29.5	7.5
24-Aug-12	11:30	169	1.42	6.00	15.0	9.7	24.00	7.5	28.6	5.9	29.0	7.5
27-Aug-12	11:15	172	1.50	4.50	13.5	9.7	24.00	7.6	26.5	7.2	26.7	7.5
29-Aug-12	8:30	174	OFF	0.00	0.0	9.5	23.50	7.3	26.2	4.8	26.3	7.0
29-Aug-12	10:45	174	OFF	0.00	0.0	9.5	23.50	7.7	26.6	3.6	26.6	7.5
29-Aug-12	12:00	174	1.50	7	16.0	9.6	24.00	7.7	26.2	6.9	26.4	7.5
30-Aug-12	7:50	175	1.40	5	14.0	9.7	24.00	7.6	25.6	7.3	25.7	7.0
1-Sep-12	17:00	177	1.42	4	12.0	9.7	23.00	7.8	27.0	6.4	27.3	7.0
2-Sep-12	11:30	178	OFF	0	0.0	9.6	23.00	7.5	28.3	4.9	28.3	7.5
2-Sep-12	15:00	178	1.46	8	18.0	9.7	23.00	7.6	28.1	6.6	28.4	7.0
5-Sep-12	12:45	181	1.49	4	14.0	9.7	23.00	7.8	27.0	6.9	27.2	7.0
6-Sep-12	8:05	182	1.45	3.5	12.0	9.7	23.0	7.6	26.3	7.9	26.4	7.5
10-Sep-12	11:00	186	1.50	4.0	13.5	9.7	23.0	7.6	25.9	6.8	26.1	8.0

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR												
Date	Time	Elapsed Time	Feed Flow FIT-101	System Feed Pressure PI-101	P-101 Discharge Pressure PI-102	Fluidization Flow FIT-102	FBR Influent Pump Discharge Pressure PI-103	System pH AIT-105	System Temperature AIT-105	Effluent D.O. AIT-103	Effluent Temperature AIT-103	FBR Fluidization Pressure PI-104
d/m/y	hh: mm	Days	gpm	psig	psig	gpm	psig	pH unit	^{o}C	mg/l	^{o}C	psig
12-Sep-12	10:30	188	1.42	3.0	12.0	9.7	23.0	7.1	25.0	7.2	25.2	8.0
12-Sep-12	11:00	188	1.4	3.0	12.0	9.7	23.0	7.2	25.1	7.1	25.3	8.0
14-Sep-12	7:30	190	OFF	0.0	0.0	9.5	22.0	7.3	27.3	5.0	27.4	8.0
14-Sep-12	9:15	190	OFF	0.0	0.0	9.4	22.0	7.3	27.4	4.2	27.5	8.0
15-Sep-12	9:30	191	OFF	0.0	0.0	9.4	22.0	7.1	28.1	4.9	28.1	8.0
15-Sep-12	11:10	191	OFF	0.0	0.0	9.5	22.0	7.1	28.1	4.2	28.2	8.0
17-Sep-12	15:30	193	OFF	0.0	0.0	9.2	22.0	7.1	29.8	5.1	30.0	7.5
17-Sep-12	17:30	193	OFF	0.0	0.0	9.3	22.0	7.3	30.0	4.6	30.2	7.5
19-Sep-12	9:45	195	1.4	3.0	12.0	9.7	23.0	7.4	26.4	7.3	26.7	8.0
20-Sep-12	9:35	196	1.5	3.0	12.0	9.6	23.0	7.7	24.7	7.8	24.8	7.5
24-Sep-12	11:00	200	1.5	3.5	12.5	9.7	22.5	7.3	24.7	7.3	24.7	8.0
26-Sep-12	10:30	202	1.5	3.5	12.5	9.6	22.5	7.3	24.5	6.5	24.6	8.0
28-Sep-12	9:20	204	2.1	2.5	11.0	9.7	22.5	7.3	25.3	7.8	25.4	8.0
29-Sep-12	11:00	205	2.2	2.5	11.0	9.7	23.0	7.9	24.0	5.9	24.2	8.0
1-Oct-12	9:45	207	2.3	2.5	11.5	9.7	22.5	7.8	23.3	6.4	23.4	8.0
2-Oct-12	10:35	208	2.2	3.0	11.5	9.7	22.5	7.8	24.4	6.7	24.5	7.8
3-Oct-12	9:00	209	2.2	3.5	12.0	9.7	22.5	7.5	23.8	6.3	23.9	8.0
3-Oct-12	11:00	209	2.2	3.5	12.0	9.7	22.5	7.5	23.9	6.5	24.0	8.0
4-Oct-12	9:30	210	2.1	2.5	11.0	9.8	22.5	7.7	23.8	6.1	23.8	8.0
8-Oct-12	9:00	214	2.1	2.5	11.0	9.7	22.5	7.6	23.5	6.3	23.6	8.0
9-Oct-12	15:00	215	2.2	2.5	11.5	9.7	22.5	7.8	24.4	5.4	24.5	7.8
10-Oct-12	11:45	216	2.2	2.5	11.5	9.7	22.5	7.4	23.9	7.4	24.1	7.8
11-Oct-12	12:00	217	2.1	2.5	11.0	9.7	22.5	7.5	24.0	6.0	24.1	7.8
15-Oct-12	12:00	221	2.2	2.5	11.5	9.7	22.0	7.3	23.9	6.6	24.0	7.8

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR

Date	Time	Elapsed Time	Feed Flow FIT-101	System Feed Pressure PI-101	P-101 Discharge Pressure PI-102	Fluidization Flow FIT-102	FBR Influent Pump Discharge Pressure PI-103	System pH AIT-105	System Temperature AIT-105	Effluent D.O. AIT-103	Effluent Temperature AIT-103	FBR Fludization Pressure PI-104
d/m/y	hh:mm	Days	gpm	psig	psig	gpm	psig	pH unit	^{o}C	mg/l	^{o}C	psig
15-Oct-12	13:00	221	2.2	2.5	11.5	9.7	22.0	7.3	24.3	6.8	24.5	7.8
17-Oct-12	11:00	223	2.2	2.5	12.0	9.7	21.5	7.2	23.5	7.3	23.6	7.9
17-Oct-12	12:00	223	2.1	2.5	11.5	9.7	22.0	7.2	23.6	6.8	23.7	7.8
19-Oct-12	8:00	225	2.1	2.0	11.0	9.7	22.0	6.9	22.5	7.0	22.6	8.0
19-Oct-12	11:50	225	2.2	2.5	11.5	9.7	22.0	7.0	23.1	6.7	23.2	8.0
22-Oct-12	10:10	228	2.2	2.5	11.5	9.5	21.5	7.5	23.8	6.1	23.9	8.0
22-Oct-12	12:30	228	2.2	2.5	11.5	9.6	22.0	7.5	24.0	6.7	24.1	8.0
24-Oct-12	12:00	230	2.2	2.5	11.5	9.5	21.5	7.4	24.2	6.7	24.2	8.0
25-Oct-12	8:15	231	2.2	3.0	11.5	9.5	21.5	7.2	22.8	7.2	22.8	8.5
25-Oct-12	11:15	231	2.2	3.0	11.5	9.6	21.8	7.3	23.0	6.8	23.2	8.0
27-Oct-12	14:45	233	2.1	2.5	11.0	9.6	22.0	7.0	23.5	6.7	23.5	8.0
29-Oct-12	11:00	235	2.2	3.0	11.5	9.6	22.0	7.0	23.0	6.8	23.1	8.5
29-Oct-12	12:30	235	2.1	2.5	11.0	9.6	22.0	7.0	23.1	6.2	23.2	8.0
31-Oct-12	8:35	237	2.1	2.5	11.5	9.5	22.0	7.1	22.4	6.3	22.5	8.5
31-Oct-12	12:45	237	2.2	3.0	12.0	9.7	23.5	8.0	23.5	6.2	23.5	8.0
2-Nov-12	7:45	239	2.2	3.0	11.5	9.7	23.8	7.9	22.6	6.6	22.7	8.5
2-Nov-12	11:40	239	4.2	1.0	7.0	9.7	24.0	7.3	23.3	6.4	23.3	8.0
5-Nov-12	10:15	242	4.4	0.5	7.5	9.7	24.0	7.2	22.7	6.9	22.8	8.0
5-Nov-12	12:15	242	4.3	0.5	7.0	9.7	24.0	7.2	23.2	6.2	23.2	8.0
7-Nov-12	9:00	244	4.4	0.0	7.5	9.6	24.0	7.6	22.8	6.3	22.8	8.5
7-Nov-12	2:00	244	4.3	0.5	7.0	9.5	24.0	7.7	23.9	4.9	24.0	8.0
9-Nov-12	8:30	246	4.2	0.5	7.5	9.6	24.0	7.4	23.0	5.1	23.1	8.5
9-Nov-12	11:20	246	4.3	0.0	7.0	9.6	24.0	7.5	23.8	6.4	23.9	8.0
12-Nov-12	8:00	249	4.4	0.5	8.0	9.6	24.0	8.2	21.0	7.6	20.9	8.5

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR												
Date	Time	Elapsed Time	Feed Flow FIT-101	System Feed Pressure PI-101	P-101 Discharge Pressure PI-102	Fluidization Flow FIT-102	FBR Influent Pump Discharge Pressure PI-103	System pH AIT-105	System Temperature AIT-105	Effluent D.O. AIT-103	Effluent Temperature AIT-103	FBR Fludization Pressure PI-104
d/m/y	hh:mm	Days	gpm	psig	psig	gpm	psig	pH unit	°C	mg/l	°C	psig
12-Nov-12	13:30	249	4.3	0.5	7.5	9.6	24.0	8.2	22.2	6.1	22.3	8.5
14-Nov-12	10:45	251	4.3	0.5	7.5	9.7	24.0	7.7	21.9	5.7	21.8	9.0
14-Nov-12	12:30	251	4.3	0.5	7.5	9.7	24.0	7.7	22.1	5.4	22.0	8.5
16-Nov-12	8:50	253	4.3	0.0	8.0	9.7	24.0	7.4	22.5	4.9	22.5	8.5
16-Nov-12	10:50	253	4.4	0.5	8.0	9.7	24.0	7.5	22.8	4.7	22.9	8.5
19-Nov-12	10:40	256	4.3	0.0	7.0	9.7	24.0	7.4	22.8	4.9	22.9	8.5
19-Nov-12	12:25	256	4.3	0.0	7.5	9.7	24.0	7.6	23.5	4.3	23.6	8.5
21-Nov-12	7:30	258	4.2	0.5	7.5	9.6	24.0	8.2	22.5	4.3	22.5	8.5
21-Nov-12	10:30	258	4.3	0.0	7.5	9.7	24.0	8.2	23.0	4.8	23.1	8.5
24-Nov-12	15:35	261	4.3	0.0	7.5	9.6	24.0	8.0	23.1	4.9	23.2	8.5
26-Nov-12	9:30	263	4.2	0.5	7.5	9.6	24.0	7.5	22.4	4.9	22.5	8.5
26-Nov-12	11:30	263	4.3	0.0	7.5	9.7	24.0	7.6	22.8	5.1	22.9	8.5
28-Nov-12	10:15	265	4.3	0.0	7.5	9.6	24.0	7.3	22.4	4.7	22.5	8.5
28-Nov-12	12:05	265	4.3	0.0	7.5	9.6	24.0	7.5	22.7	4.4	22.7	8.5
30-Nov-12	8:50	267	4.2	0.0	7.3	9.7	24.0	8.2	21.8	4.4	21.8	8.5
30-Nov-12	12:00	267	4.3	0.0	7.5	9.7	24.0	8.3	23.0	3.9	23.1	8.5
3-Dec-12	7:50	270	4.3	0.0	7.5	9.6	23.5	7.5	22.2	5.6	22.3	8.5
3-Dec-12	12:30	270	4.3	0.0	7.5	9.6	23.5	7.8	23.0	6.9	23.0	8.5
5-Dec-12	11:00	272	4.4	0.0	8.0	9.6	23.5	7.8	22.5	5.4	22.4	8.0
8-Dec-12	11:15	275	4.3	0.0	7.5	9.6	23.5	7.7	22.6	5.3	22.7	8.5
10-Dec-12	11:00	277	4.3	0.0	7.5	9.8	24.0	7.8	21.0	6.1	21.1	8.0
12-Dec-12	10:30	279	4.3	0.0	7.5	9.7	24.5	8.3	21.2	6.0	21.3	8.0
12-Dec-12	12:15	279	4.3	0.0	7.5	9.7	24.0	8.5	22.1	6.6	22.1	8.0
14-Dec-12	7:00	281	4.3	0.0	7.5	9.8	24.0	8.4	23.0	5.8	23.1	8.0

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR												
Date	Time	Elapsed Time	Feed Flow FIT-101	System Feed Pressure PI-101	P-101 Discharge Pressure PI-102	Fluidization Flow FIT-102	FBR Influent Pump Discharge Pressure PI-103	System pH AIT-105	System Temperature AIT-105	Effluent D.O. AIT-103	Effluent Temperature AIT-103	FBR Fludization Pressure PI-104
d/m/y	hh: mm	Days	gpm	psig	psig	gpm	psig	pH unit	°C	mg/l	°C	psig
14-Dec-12	9:20	281	4.3	0.0	7.0	9.7	23.5	8.3	23.0	5.8	23.1	8.0
17-Dec-12	12:25	284	4.3	0.0	7.5	9.7	23.5	8.4	22.2	7.3	22.3	8.0
17-Dec-12	2:05	284	4.3	0.0	7.5	9.7	23.5	8.4	22.5	6.2	22.6	8.0
19-Dec-12	9:20	286	4.3	0.0	7.5	9.7	23.5	8.2	22.2	5.8	22.3	8.0
19-Dec-12	1:50	286	4.3	0.0	7.5	9.7	24.0	8.4	21.8	6.4	21.9	8.0
20-Dec-12	8:45	287	OFF	0.0	0.0	9.2	22.5	8.1	20.7	5.4	20.7	8.5
2-Jan-13	9:30	300	OFF	0.0	0.0	9.5	22.0	7.2	29.1	4.7	28.9	8.5
2-Jan-13	11:45	300	OFF	0.0	0.0	9.6	22.5	7.2	29.2	4.9	29.1	8.0
3-Jan-13	8:30	301	OFF	0.0	0.0	9.5	22.5	7.3	28.8	4.7	28.7	8.5
7-Jan-13	8:45	305	OFF	0.0	0.0	9.4	23.0	7.1	29.2	3.9	29.8	8.5
9-Jan-13	12:45	307	OFF	0.0	0.0	9.2	23.0	6.9	30.9	5.6	30.9	8.5
9-Jan-13	2:40	307	OFF	0.0	0.0	9.2	23.0	6.9	31.0	4.9	30.9	8.5
11-Jan-13	8:45	309	OFF	0.0	0.0	9.1	23.0	7.0	31.6	5.0	31.5	8.5
14-Jan-13	8:15	312	OFF	0.0	0.0	9.0	23.0	7.2	28.6	5.0	28.7	8.5
14-Jan-13	10:00	312	OFF	0.0	0.0	9.1	23.0	7.2	28.6	5.0	28.4	8.5
16-Jan-13	9:15	314	OFF	0.0	0.0	9.0	23.0	7.3	26.8	4.5	26.7	9.0
17-Jan-13	3:15	315	OFF	0.0	0.0	9.0	22.5	7.2	28.8	4.9	28.7	9.0
17-Jan-13	5:30	315	4.4	0.5	9.0	9.6	24.0	6.9	17.8	6.4	18.2	8.0
18-Jan-13	11:45	316	4.3	0.0	7.0	9.6	24.0	7.3	19.6	8.0	19.8	8.0
20-Jan-13	1:30	318	4.4	0.0	8.0	9.7	24.0	7.9	17.9	6.9	18.0	8.5
22-Jan-13	7:00	320	4.2	0.0	9.0	9.7	24.0	7.5	17.8	7.2	17.9	8.5
22-Jan-13	11:30	320	4.4	0.0	7.0	9.7	24.0	7.4	15.1	8.0	15.6	8.5
24-Jan-13	11:00	322	4.4	0.0	7.0	9.7	24.0	7.7	19.4	6.2	19.5	8.5
25-Jan-13	8:00	323	4.2	0.0	7.0	9.7	24.0	7.6	20.4	7.0	20.5	8.0

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR												
Date	Time	Elapsed Time	Feed Flow FIT-101	System Feed Pressure PI-101	P-101 Discharge Pressure PI-102	Fluidization Flow FIT-102	FBR Influent Pump Discharge Pressure PI-103	System pH AIT-105	System Temperature AIT-105	Effluent D.O. AIT-103	Effluent Temperature AIT-103	FBR Fludization Pressure PI-104
d/m/y	hh: mm	Days	gpm	psig	psig	gpm	psig	pH unit	^{o}C	mg/l	^{o}C	psig
25-Jan-13	10:00	323	4.4	0.0	7.0	9.7	24.0	7.6	20.7	6.3	20.8	8.0
28-Jan-13	10:15	326	4.3	0.0	7.0	9.7	24.0	7.7	22.6	6.9	22.4	8.0
28-Jan-13	12:20	326	4.4	0.0	7.0	9.7	24.0	7.6	22.7	6.0	22.5	8.0
30-Jan-13	10:30	328	4.1	0.5	8.0	9.7	24.0	8.0	20.8	6.0	21.0	8.0
30-Jan-13	12:30	328	4.2	0.0	8.0	9.7	24.0	8.0	21.0	5.9	21.1	8.0
1-Feb-13	8:20	330	4.1	0.5	8.0	9.7	24.0	7.6	20.6	5.5	20.8	8.0
1-Feb-13	10:40	330	4.2	0.0	7.5	9.7	24.0	7.7	21.4	5.6	21.6	8.0
4-Feb-13	9:10	333	4.2	0.0	8.0	9.7	24.0	7.3	21.7	6.1	21.9	8.0
4-Feb-13	11:40	333	4.3	0.0	7.5	9.7	24.0	7.4	22.1	5.9	22.3	8.0
7-Feb-13	7:50	336	4.2	0.0	7.5	9.5	24.0	8.1	21.7	4.4	21.8	8.0
7-Feb-13	11:30	336	4.2	0.0	7.5	9.6	24.0	8.1	21.9	5.5	22.0	8.0
8-Feb-13	10:30	337	4.3	0.0	7.5	9.7	24.0	8.1	22.3	5.2	22.5	8.0
20-Feb-13	11:00	349	4.3	0.0	7.5	9.6	24.5	8.4	22.2	5.2	22.4	8.0
25-Feb-13	15:15	354	4.3	0.0	6.5	9.7	26.0	7.9	23.9	5.7	23.8	8.0
27-Feb-13	11:35	356	4.3	0.0	6.5	9.7	26.0	7.3	24.3	6.3	24.4	8.0
28-Feb-13	10:00	357	4.1	0.0	7.0	9.7	26.5	7.2	24.0	6.2	24.1	8.0
28-Feb-13	12:30	357	4.3	0.0	7.5	9.7	26.5	7.2	24.2	6.1	24.4	8.0
4-Mar-13	11:30	361	4.4	0.0	7.0	9.6	26.5	7.0	25.0	5.9	25.1	8.0
6-Mar-13	7:40	363	4.4	0.0	6.5	9.7	26.5	7.0	24.4	6.1	24.6	8.0
6-Mar-13	10:20	363	4.3	0.0	7.0	9.7	26.5	7.0	24.6	6.3	24.8	8.0
8-Mar-13	8:30	365	4.4	0.0	6.5	9.7	26.5	7.5	24.7	5.1	24.8	8.0
8-Mar-13	10:15	365	4.3	0.0	7.0	9.7	26.5	7.6	24.8	5.0	25.0	8.0
11-Mar-13	10:15	368	OFF	0.0	0.0	9.4	26.0	7.2	30.4	5.0	30.6	8.0
11-Mar-13	12:15	368	4.4	0.0	6.0	9.7	26.0	7.3	23.9	5.1	25.1	8.0

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR												
Date	Time	Elapsed Time	Feed Flow FIT-101	System Feed Pressure PI-101	P-101 Discharge Pressure PI-102	Fluidization Flow FIT-102	FBR Influent Pump Discharge Pressure PI-103	System pH AIT-105	System Temperature AIT-105	Effluent D.O. AIT-103	Effluent Temperature AIT-103	FBR Fludization Pressure PI-104
d/m/y	hh: mm	Days	gpm	psig	psig	gpm	psig	pH unit	^{o}C	mg/l	^{o}C	psig
13-Mar-13	1:15	370	4.3	0.0	6.5	9.7	26.0	7.3	25.2	5.6	25.4	8.0
14-Mar-13	9:52	371	4.4	0.0	6.0	9.7	26.5	7.3	23.8	4.6	24.0	8.0
15-Mar-13	7:30	372	4.4	0.0	6.0	9.6	26.5	7.3	24.4	5.8	24.4	8.0
15-Mar-13	10:45	372	4.4	0.0	6.0	9.6	26.5	7.3	24.6	4.7	24.8	8.0
18-Mar-13	9:45	375	4.4	0.0	6.0	9.6	26.5	7.3	25.6	6.5	25.8	8.0
18-Mar-13	12:00	375	4.4	0.0	6.0	9.6	26.0	7.4	25.8	5.6	26.0	8.0
20-Mar-13	6:30	377	4.3	0.0	6.5	9.7	26.0	7.4	24.6	5.7	24.8	8.0

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR														
Date	Time	Elapsed Time	Settled Bed Height	FBR Bed Height	Settled Bed Depth from Top of vessel	Fluidized Bed Depth from Top of vessel	Percent Fluidization	Sweep Air /Biomass Separator Air Pressure (PRV-185)	Biomass Separator Flow Rate FI-185	Sweep Air Flow Rate FI-186	Nutrient Tank Feed Tank Volume T-106 (urea)	Nutrient Feed Pump Speed P-106(urea)	Nutrient Tank Feed Tank Volume T-107 (DAP)	Nutrient Feed Pump Speed P-107 (DAP)
d/m/y	hh:mm	Days	in.	in.	in.	in.	%	psig	scfh	scfh	gallons	%	gallons	%
8-Mar-12	9:02	0	69.5	88	71.5	53	26.6%	14.0	5.5	5.4	N/A	N/A	N/A	N/A
12-Mar-12	8:27	4	69.5	88.5	71.5	52.5	27.3%	13.0	5.3	5.0	N/A	N/A	N/A	N/A
12-Mar-12	11:00	4	69.5	88.5	71.5	52.5	27.3%	13.5	5.3	5.0	N/A	N/A	N/A	N/A
14-Mar-12	8:28	6	69.5	88	71.5	53	26.6%	13.6	5.0	4.8	N/A	N/A	N/A	N/A
16-Mar-12	9:30	8	69.5	88	71.5	53	26.6%	13.6	5.0	4.8	N/A	N/A	N/A	N/A
19-Mar-12	10:00	11	69.5	88	71.5	53	26.6%	13.6	5.0	4.8	N/A	N/A	N/A	N/A
21-Mar-12	8:05	13	69.5	88	71.5	53	26.6%	13.8	5.0	5.0	N/A	N/A	N/A	N/A
23-Mar-12	12:00	15	69.5	88	71.5	53	26.6%	13.4	4.8	4.8	N/A	N/A	N/A	N/A
26-Mar-12	15:30	18	69.5	88	71.5	53	26.6%	13.4	4.8	4.8	N/A	N/A	N/A	N/A
27-Mar-12	8:00	19	69.5	88	71.5	53	26.6%	13.5	4.9	4.9	N/A	N/A	N/A	N/A
27-Mar-12	11:33	19	69.5	88	71.5	53	26.6%	13.5	5.0	5.3	N/A	N/A	N/A	N/A
30-Mar-12	12:45	22	69.5	88	71.5	53	26.6%	13.2	4.8	5.2	N/A	N/A	N/A	N/A
2-Apr-12	16:00	25	69.5	88	71.5	53	26.6%	13.4	5.2	5.3	N/A	N/A	N/A	N/A
4-Apr-12	8:00	27	69.5	88	71.5	53	26.6%	13.4	5.2	5.3	N/A	N/A	N/A	N/A
5-Apr-12	9:30	28	69.5	88	71.5	53	26.6%	13.4	5.2	5.3	N/A	N/A	N/A	N/A
10-Apr-12	9:15	33	69.5	88	71.5	53	26.6%	13.4	5.1	5.3	N/A	N/A	N/A	N/A
16-Apr-12	13:30	39	69.5	87.5	71.5	53.5	25.9%	14.0	7.0	8.4	N/A	N/A	N/A	N/A
18-Apr-12	12:30	41	69.5	87.5	71.5	53.5	25.9%	14.0	6.5	8.3	N/A	N/A	N/A	N/A
19-Apr-12	10:30	42	69.5	87.5	71.5	53.5	25.9%	14.0	6.5	8.3	N/A	N/A	N/A	N/A
24-Apr-12	9:08	47	69.5	84	71.5	57	20.9%	14.0	6.5	8.4	N/A	N/A	N/A	N/A
26-Apr-12	12:00	49	69	84	72	57	21.7%	14.0	6.4	8.4	N/A	N/A	N/A	N/A
30-Apr-12	10:15	53	69	84	72	57	21.7%	14.0	6.4	8.4	N/A	N/A	N/A	N/A
30-Apr-12	14:00	53	69	86	72	55	24.6%	14.0	6.4	8.4	N/A	N/A	N/A	N/A
30-Apr-12	15:00	53	69	86.5	72	54.5	25.4%	14.0	6.4	8.4	N/A	N/A	N/A	N/A

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR														
Date	Time	Elapsed Time	Settled Bed Height	FBR Bed Height	Settled Bed Depth from Top of vessel	Fluidized Bed Depth from Top of vessel	Percent Fluidization	Sweep Air /Biomass Separator Air Pressure (PRV-185)	Biomass Separator Flow Rate FI-185	Sweep Air Flow Rate FI-186	Nutrient Tank Feed Tank Volume T-106 (urea)	Nutrient Feed Pump Speed P-106(urea)	Nutrient Tank Feed Tank Volume T-107 (DAP)	Nutrient Feed Pump Speed P-107 (DAP)
d/m/y	hh:mm	Days	in.	in.	in.	in.	%	psig	scfh	scfh	gallons	%	gallons	%
1-May-12	15:30	54	69	86.5	72	54.5	25.4%	14.0	6.4	7.5	N/A	N/A	N/A	N/A
3-May-12	11:15	56	69	86.5	72	54.5	25.4%	13.6	7.0	7.5	N/A	N/A	N/A	N/A
3-May-12	12:00	56	69	88	72	53	27.5%	13.6	6.4	7.4	N/A	N/A	N/A	N/A
3-May-12	13:30	56	69	87.5	72	53.5	26.8%	13.6	6.4	7.4	N/A	N/A	N/A	N/A
7-May-12	11:15	60	69	86.5	72	54.5	25.4%	13.2	6.3	7.3	N/A	N/A	N/A	N/A
10-May-12	16:45	63	69	87	72	54	26.1%	13.2	7.0	7.2	N/A	N/A	N/A	N/A
14-May-12	8:15	67	69	83	72	58	20.3%	13.0	6.4	7.3	N/A	N/A	N/A	N/A
14-May-12	12:15	67	69	87	72	54	26.1%	13.0	6.2	7.1	N/A	N/A	N/A	N/A
15-May-12	15:00	68	69	86	72	55	24.6%	13.0	8.0	8.2	N/A	N/A	N/A	N/A
21-May-12	14:15	74	69	87	72	54	26.1%	14.0	9.2	9.0	N/A	N/A	N/A	N/A
22-May-12	16:00	75	69	87	72	54	26.1%	13.4	9.4	9.1	N/A	N/A	N/A	N/A
23-May-12	12:30	76	69	87	72	54	26.1%	13.6	9.4	9.3	N/A	N/A	N/A	N/A
25-May-12	12:00	78	69	87	72	54	26.1%	13.6	9.4	9.3	N/A	N/A	N/A	N/A
29-May-12	12:50	82	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
30-May-12	13:05	83	69	84	72	57	21.7%	13.5	9.3	9.3	0.0	42.1	0.0	42.1
30-May-12	14:50	83	69	84	72	57	21.7%	14.2	0.0	8.5	0.0	42.1	0.0	42.1
30-May-12	16:08	83	69	84	72	57	21.7%	13.0	8.5	9.5	0.0	42.1	0.0	42.1
31-May-12	8:00	84	69	84.5	72	56.5	22.5%	13.0	8.4	9.5	0.0	42.1	0.0	42.1
31-May-12	9:15	84	69	84.5	72	56.5	22.5%	13.0	8.4	9.5	0.0	42.1	0.0	42.1
31-May-12	10:30	84	N/A	N/A	N/A	N/A	N/A	13.0	8.4	9.5	0.0	42.1	0.0	42.1
31-May-12	11:45	84	69	85	72	56	23.2%	13.0	8.4	9.4	0.0	42.1	0.0	42.1
31-May-12	14:00	84	69	84.5	72	56.5	22.5%	13.0	8.4	9.4	0.0	42.1	0.0	42.1
31-May-12	14:30	84	69	84	72	57	21.7%	13.0	8.3	9.3	0.0	42.1	0.0	42.1
1-Jun-12	7:15	85	69	83	72	58	20.3%	13.0	8.3	9.3	0.0	42.1	0.0	42.1

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR														
Date	Time	Elapsed Time	Settled Bed Height	FBR Bed Height	Settled Bed Depth from Top of vessel	Fluidized Bed Depth from Top of vessel	Percent Fluidization	Sweep Air /Biomass Separator Air Pressure (PRV-	Biomass Separator Flow Rate FI-185	Sweep Air Flow Rate FI-186	Nutrient Tank Feed Tank Volume T-106 (urea)	Nutrient Feed Pump Speed P-106(urea)	Nutrient Tank Feed Tank Volume T-107 (DAP)	Nutrient Feed Pump Speed P-107 (DAP)
d/m/y	hh:mm	Days	in.	in.	in.	in.	%	psig	scfh	scfh	gallons	%	gallons	%
1-Jun-12	10:00	85	69	84	72	57	21.7%	13.0	8.3	9.3	42.1	0	42.1	0
1-Jun-12	12:00	85	69	84.4	72	56.6	22.3%	13.0	8.1	9.4	42.1	0	42.1	0
2-Jun-12	9:00	86	69	84	72	57	21.7%	13.0	7.5	9.5	42.1	0	42.1	0
2-Jun-12	10:30	86	69	84	72	57	21.7%	13.2	7.0	9.0	42.1	0	42.1	0
2-Jun-12	11:30	86	69	84	72	57	21.7%	13.2	6.5	9.5	42.1	0	42.1	0
2-Jun-12	12:30	86	69	84	72	57	21.7%	13.2	6.5	9.5	42.1	0	42.1	0
4-Jun-12	8:30	88	69	84.5	72	56.5	22.5%	14.0	2.0	9.5	42.1	0	42.1	0
4-Jun-12	13:30	88	69	84.5	72	56.5	22.5%	14.0	2.8	9.5	42.1	0	42.1	0
5-Jun-12	14:30	89	69	84.5	72	56.5	22.5%	14.0	6.0	9.5	42	0	42	0
6-Jun-12	9:00	90	69	84	72	57	21.7%	13.6	6.0	9.5	42	0	42	0
6-Jun-12	13:07	90	69	84.5	72	56.5	22.5%	13.6	6.5	9.0	42	3.5	42	4.3
6-Jun-12	15:40	90	69	84.5	72	56.5	22.5%	13.6	6.5	9.0	42	3.5	42	4.3
7-Jun-12	8:05	91	69	86	72	55	24.6%	13.6	6.5	9.0	36.3	3.5	36.3	4.3
7-Jun-12	10:40	91	69	141	72		104.3%	N/A	N/A	N/A	N/A	N/A	N/A	N/A
7-Jun-12	12:00	91	69	87	72	54	26.1%	13.6	6.4	8.9	35.8	3.5	35.8	4.3
7-Jun-12	13:20	91	69	87	72	54	26.1%	13.6	6.4	8.9	34.7	3.5	34.7	4.3
8-Jun-12	8:00	92	69	87.5	72	53.5	26.8%	13.2	7.5	8.5	28.9	3.5	28.9	4.3
8-Jun-12	10:30	92	69	87.5	72	53.5	26.8%	13.2	7.5	8.5	41.6	3.8	41.6	4.3
8-Jun-12	12:15	92	69	87.5	72	53.5	26.8%	13.2	8.0	8.5	41.3	4	41.3	4.3
8-Jun-12	13:00	92	69	87.5	72	53.5	26.8%	13.2	8.0	8.5	41.3	4	41.3	4.3
8-Jun-12	14:00	92	69	87.5	72	53.5	26.8%	13.2	8.0	8.5	41.1	4.3	41.1	4.3
9-Jun-12	10:40	93	69	88	72	53	27.5%	13.4	7.5	8.6	34.2	4.3	35	4.3
9-Jun-12	12:00	93	69	88	72	53	27.5%	13.4	7.5	8.6	34.2	5.3	35	4.3

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR														
Date	Time	Elapsed Time	Settled Bed Height	FBR Bed Height	Settled Bed Depth from Top of vessel	Fluidized Bed Depth from Top of vessel	Percent Fluidization	Sweep Air /Biomass Separator Air Pressure (PRV-	Biomass Separator Flow Rate FI-185	Sweep Air Flow Rate FI-186	Nutrient Tank Feed Tank Volume T-106 (urea)	Nutrient Feed Pump Speed P-106(urea)	Nutrient Tank Feed Tank Volume T-107 (DAP)	Nutrient Feed Pump Speed P-107 (DAP)
d/m/y	hh:mm	Days	in.	in.	in.	in.	%	psig	scfh	scfh	gallons	%	gallons	%
9-Jun-12	13:00	93	69	88	72	53	27.5%	13.4	7.5	8.6	33.9	6.0	34.7	4.3
9-Jun-12	14:00	93	69	88	72	53	27.5%	13.4	7.5	8.6	33.9	6.0	34.7	4.3
9-Jun-12	15:00	93	69	88	72	53	27.5%	13.4	7.5	8.6	33.4	6.0	34.2	4.3
11-Jun-12	7:50	95	69	88	72	53	27.5%	13.4	7.5	8.6	11.8	6.0	18.4	4.3
11-Jun-12	11:30	95	69	88.5	72	52.5	28.3%	13.4	7.5	8.6	42.1	6.0	42.1	4.3
11-Jun-12	13:00	95	69	88.5	72	52.5	28.3%	13.4	7.5	8.6	41.8	6.0	42.0	4.3
11-Jun-12	14:00	95	69	88.5	72	52.5	28.3%	13.4	7.5	8.6	41.1	7.0	41.6	5.0
13-Jun-12	8:00	97	69	89	72	52	29.0%	13.4	7.5	8.6	16.3	7.0	23.7	5.0
13-Jun-12	13:40	97	69	89	72	52	29.0%	13.4	7.5	8.6	42.1	7.8	42.1	6.0
13-Jun-12	15:00	97	69	89	72	52	29.0%	13.4	7.5	8.6	42.1	7.8	42.1	6.0
14-Jun-12	8:30	98	69	89	72	52	29.0%	13.4	7.5	8.6	32.9	7.8	34.2	6.0
14-Jun-12	9:00	98	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
14-Jun-12	11:00	98	69	89	72	52	29.0%	13.4	7.5	8.6	31.6	8.5	32.9	7.0
15-Jun-12	8:00	99	69	89	72	52	29.0%	13.4	7.5	8.6	16.3	8.5	20.5	7.0
15-Jun-12	12:15	99	69	89	72	52	29.0%	13.4	7.5	8.6	42.1	4.0	42.1	3.5
16-Jun-12	22:00	100	69	89	72	52	29.0%	13.4	7.5	8.6	30.3	4.0	31.6	3.5
18-Jun-12	11:00	102	69	89.5	72	51.5	29.7%	13.4	7.5	8.6	20.0	4.0	23.7	3.5
20-Jun-12	10:00	104	69	89.5	72	51.5	29.7%	13.4	7.5	8.6	3.9	4.0	12.1	3.5
20-Jun-12	12:20	104	69	89.5	72	51.5	29.7%	13.4	7.5	8.6	43.4	4.5	43.4	3.5
22-Jun-12	9:00	106	69	90	72	51	30.4%	13.4	7.5	8.6	30.3	4.5	34.2	3.5
25-Jun-12	12:00	109	69	90	72	51	30.4%	13.4	7.5	8.6	42.1	4.5	42.1	3.5
27-Jun-12	9:00	111	69	90	72	51	30.4%	13.4	7.2	8.4	27.6	4.5	32.9	3.5
27-Jun-12	12:30	111	69	90	72	51	30.4%	13.4	7.2	8.4	26.8	4.5	32.4	3.5
28-Jun-12	10:25	112	69	90.5	72	50.5	31.2%	13.6	7.3	8.5	43.4	4.5	43.4	3.5

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR														
Date	Time	Elapsed Time	Settled Bed Height	FBR Bed Height	Settled Bed Depth from Top of vessel	Fluidized Bed Depth from Top of vessel	Percent Fluidization	Sweep Air /Biomass Separator Air Pressure (PRV-	Biomass Separator Flow Rate FI-185	Sweep Air Flow Rate FI-186	Nutrient Tank Feed Tank Volume T-106 (urea)	Nutrient Feed Pump Speed P-106(urea)	Nutrient Tank Feed Tank Volume T-107 (DAP)	Nutrient Feed Pump Speed P-107 (DAP)
d/m/y	hh:mm	Days	in.	in.	in.	in.	%	psig	scfh	scfh	gallons	%	gallons	%
2-Jul-12	11:15	116	69	90	72	51	30.4%	13.6	7.3	8.5	23.7	4.5	28.9	3.5
3-Jul-12	8:45	117	69	90	72	51	30.4%	13.6	7.3	8.5	16.3	4.5	23.7	3.5
5-Jul-12	9:30	119	69	90	72	51	30.4%	13.6	7.3	8.5	42.1	4.5	42.1	5.0
7-Jul-12	17:45	121	69	91	72	50	31.9%	13.6	7.5	8.8	27.6	4.5	25.0	5.0
9-Jul-12	12:15	123	69	91.5	72	49.5	32.6%	13.6	7.5	8.8	42.1	4.5	43.4	5.0
11-Jul-12	10:40	125	69	91.5	72	49.5	32.6%	13.6	7.5	8.8	26.8	4.5	26.3	5.0
12-Jul-12	8:15	126	69	91.5	72	49.5	32.6%	13.6	8.0	8.5	18.9	4.5	17.1	5.0
12-Jul-12	11:45	126	69	91.5	72	49.5	32.6%	13.6	8.0	8.5	44.7	5.3	44.7	5.0
16-Jul-12	12:00	130	69	90	72	51	30.4%	13.6	8.0	8.5	44.7	5.3	44.7	5.0
19-Jul-12	17:00	133	69	89	72	52	29.0%	13.6	8.0	8.5	43.4	5.3	43.4	5.0
20-Jul-12	11:15	134	69	90	72	51	30.4%	13.4	7.0	8.4	40.8	5.3	38.2	5.0
23-Jul-12	11:45	137	69	89.5	72	51.5	29.7%	13.2	7.3	8.3	11.8	5.3	7.9	5.0
24-Jul-12	20:45	138	69	87	72	54	26.1%	13.0	6.6	8.4	44.7	5.3	44.7	5.0
25-Jul-12	12:15	139	69	87.5	72	53.5	26.8%	13.0	6.4	8.3	40.8	5.3	42.1	5.0
25-Jul-12	13:40	139	69	87.5	72	53.5	26.8%	13.0	6.4	8.3	40.8	5.3	42.1	5.0
26-Jul-12	13:00	140	69	87.5	72	53.5	26.8%	13.0	6.6	8.2	40.8	5.25	42.1	5.0
26-Jul-12	15:00	140	69	87.5	72	53.5	26.8%	13.0	6.6	8.2	39.5	5.3	40.8	5.0
27-Jul-12	11:15	141	69	87.5	72	53.5	26.8%	13.2	7.4	8.4	34.7	5.3	36.8	5.0
30-Jul-12	9:35	144	69	87.5	72	53.5	26.8%	13.3	6.5	8.4	44.7	5.3	44.7	5.0
1-Aug-12	11:40	146	69	88	72	53	27.5%	13.6	6.0	8.5	25.0	5.3	26.3	5.0
3-Aug-12	10:45	148	69	88.5	72	52.5	28.3%	13.6	6.4	8.2	44.7	5.3	44.7	5.0
6-Aug-12	11:20	151	69	88.5	72	52.5	28.3%	13.4	7.0	8.3	15.3	5.3	17.1	5.0
8-Aug-12	8:10	153	69	88.5	72	52.5	28.3%	13.4	6.5	8.3	1.3	5.3	2.6	5.0
8-Aug-12	14:20	153	69	88.5	72	52.5	28.3%	13.4	6.5	8.3	44.7	5.3	44.7	5.0

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR														
Date	Time	Elapsed Time	Settled Bed Height	FBR Bed Height	Settled Bed Depth from Top of vessel	Fluidized Bed Depth from Top of vessel	Percent Fluidization	Sweep Air /Biomass Separator Air Pressure (PRV-185)	Biomass Separator Flow Rate FI-185	Sweep Air Flow Rate FI-186	Nutrient Tank Feed Tank Volume T-106 (urea)	Nutrient Feed Pump Speed P-106(urea)	Nutrient Tank Feed Tank Volume T-107 (DAP)	Nutrient Feed Pump Speed P-107 (DAP)
d/m/y	hh:mm	Days	in.	in.	in.	in.	%	psig	scfh	scfh	gallons	%	gallons	%
9-Aug-12	13:30	154	69	89	72	52	29.0%	13.6	6.5	8.4	43.4	5.3	44.5	5.0
13-Aug-12	8:15	158	69	89.5	72	51.5	29.7%	14.0	6.5	8.2	11.8	5.3	10.5	5.0
13-Aug-12	12:10	158	69	90	72	51	30.4%	14.0	6.5	8.2	44.7	5.3	44.7	5.0
15-Aug-12	8:21	160	69	90	72	51	30.4%	14.0	6.5	8.2	28.9	5.3	30.3	5.0
15-Aug-12	11:00	160	69	90.7	72	50.3	31.4%	13.8	6.5	8.2	27.6	5.3	28.9	5.0
16-Aug-12	12:00	161	69	91	72	50	31.9%	13.8	6.5	8.4	44.7	5.3	44.7	5.0
20-Aug-12	10:45	165	69	92	72	49	33.3%	13.8	6.5	8.4	7.9	5.3	9.2	5.0
20-Aug-12	13:00	165	69	92	72	49	33.3%	13.8	6.5	8.0	44.7	5.3	44.7	5.0
22-Aug-12	11:00	167	69	92.75	72	48.25	34.4%	13.8	6.5	7.6	26.3	5.3	27.6	5.0
23-Aug-12	11:30	168	69	92.75	72	48.25	34.4%	13.6	7.0	8.0	44.7	5.3	44.7	5.0
23-Aug-12	17:00	168	69	93	72	48	34.8%	13.6	7.0	8.0	43.4	5.3	44.2	5.0
24-Aug-12	10:05	169	69	93	72	48	34.8%	13.8	6.8	8.1	39.5	5.3	40.8	5.0
24-Aug-12	11:30	169	69	93	72	48	34.8%	13.8	6.8	8.1	38.9	5.3	40.5	5.0
27-Aug-12	11:15	172	69	93.25	72	47.75	35.1%	13.8	6.7	8.1	44.7	5.3	44.7	5.0
29-Aug-12	8:30	174	69	93	72	48	34.8%	13.8	6.7	8.2	27.6	5.3	30.5	5.0
29-Aug-12	10:45	174	69	93	72	48	34.8%	13.8	6.7	8.2	27.6	5.3	30.5	5.0
29-Aug-12	12:00	174	69	93	72	48	34.8%	13.8	6.7	8.2	27.6	5.3	30.5	5.0
30-Aug-12	7:50	175	69	93.25	72	47.75	35.1%	13.8	6.7	8.2	44.7	5.3	44.7	5.0
1-Sep-12	17:00	177	69	93	72	48	34.8%	13.8	7.8	8.2	44.7	5.3	44.7	5.0
2-Sep-12	11:30	178	69	93	72	48	34.8%	13.8	7.8	8.2	42.1	5.3	43.4	5.0
2-Sep-12	15:00	178	69	93.25	72	47.75	35.1%	13.8	7.8	8.2	42.1	5.3	43.4	5.0
5-Sep-12	12:45	181	69	94	72	47	36.2%	13.8	7.8	8.0	44.7	5.3	46.1	5.0
6-Sep-12	8:05	182	69	94	72	47	36.2%	13.8	7.8	8.1	36.8	5.3	39.5	5.0
10-Sep-12	11:00	186	69	94	72	47	36.2%	13.8	7.7	7.9	44.7	5.3	44.7	5.0

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR														
Date	Time	Elapsed Time	Settled Bed Height	FBR Bed Height	Settled Bed Depth from Top of vessel	Fluidized Bed Depth from Top of vessel	Percent Fluidization	Sweep Air /Biomass Separator Air Pressure (PRV-	Biomass Separator Flow Rate FI-185	Sweep Air Flow Rate FI-186	Nutrient Tank Feed Tank Volume T-106 (urea)	Nutrient Feed Pump Speed P-106(urea)	Nutrient Tank Feed Tank Volume T-107 (DAP)	Nutrient Feed Pump Speed P-107 (DAP)
d/m/y	hh:mm	Days	in.	in.	in.	in.	%	psig	scfh	scfh	gallons	%	gallons	%
12-Sep-12	10:30	188	69	94.5	72	46.5	37.0%	13.8	7.7	7.9	24.7	5.3	27.6	5.5
12-Sep-12	11:00	188	69	94.5	72	46.5	37.0%	13.8	7.7	7.9	25.0	5.3	27.4	5.5
14-Sep-12	7:30	190	69	93	72	48	34.8%	13.8	7.6	7.9	11.8	5.3	14.5	5.5
14-Sep-12	9:15	190	69	93	72	48	34.8%	13.8	7.6	7.9	11.8	5.3	14.5	5.5
15-Sep-12	9:30	191	69	92	72	49	33.3%	13.8	7.6	7.9	11.8	5.3	14.5	5.5
15-Sep-12	11:10	191	69	92	72	49	33.3%	13.8	7.6	7.9	11.8	5.3	14.5	5.5
17-Sep-12	15:30	193	69	91	72	50	31.9%	13.8	7.6	7.9	11.8	5.3	14.5	5.5
17-Sep-12	17:30	193	69	91	72	50	31.9%	13.8	7.6	7.9	44.7	5.3	44.7	5.5
19-Sep-12	9:45	195	69	94	72	47	36.2%	13.8	7.6	7.8	44.5	5.3	44.2	5.5
20-Sep-12	9:35	196	69	94	72	47	36.2%	13.8	7.6	7.8	34.2	5.3	35.5	5.5
24-Sep-12	11:00	200	69	93.5	72	47.5	35.5%	13.8	7.6	7.8	44.7	5.3	44.7	5.5
26-Sep-12	10:30	202	69	93.5	72	47.5	35.5%	13.8	7.7	7.9	25.0	5.3	25.8	5.5
28-Sep-12	9:20	204	69	93.5	72	47.5	35.5%	13.8	7.7	7.9	44.7	5.3	44.7	5.5
29-Sep-12	11:00	205	69	93.5	72	47.5	35.5%	13.8	7.7	7.9	39.5	5.3	40.8	5.5
1-Oct-12	9:45	207	69	93.5	72	47.5	35.5%	13.8	7.7	7.9	44.7	5.3	44.7	5.5
2-Oct-12	10:35	208	69	93.5	72	47.5	35.5%	13.6	7.6	7.7	32.9	5.3	34.2	5.5
3-Oct-12	9:00	209	69	94	72	47	36.2%	13.6	7.6	7.7	25.0	5.3	26.3	5.5
3-Oct-12	11:00	209	69	94	72	47	36.2%	13.6	7.6	7.7	24.2	6.0	25.8	6.5
4-Oct-12	9:30	210	69	94	72	47	36.2%	13.6	7.6	7.7	44.7	6.0	44.7	6.5
8-Oct-12	9:00	214	69	94	72	47	36.2%	13.6	7.6	7.7	44.7	6.0	44.7	6.5
9-Oct-12	15:00	215	69	93.5	72	47.5	35.5%	13.6	7.6	7.7	34.2	6.0	34.7	6.5
10-Oct-12	11:45	216	69	94	72	47	36.2%	13.6	7.7	7.9	22.4	6.0	22.6	6.5
11-Oct-12	12:00	217	69	94	72	47	36.2%	13.6	7.7	7.9	44.7	6.0	44.7	6.5
15-Oct-12	12:00	221	69	93.5	72	47.5	35.5%	13.6	7.7	7.9	44.7	6.0	44.7	6.5

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR

Date	Time	Elapsed Time	Settled Bed Height	FBR Bed Height	Settled Bed Depth from Top of vessel	Fluidized Bed Depth from Top of vessel	Percent Fluidization	Sweep Air /Biomass Separator Air Pressure (PRV-185)	Biomass Separator Flow Rate FI-185	Sweep Air Flow Rate FI-186	Nutrient Tank Feed Tank Volume T-106 (urea)	Nutrient Feed Pump Speed P-106(urea)	Nutrient Tank Feed Tank Volume T-107 (DAP)	Nutrient Feed Pump Speed P-107 (DAP)
d/m/y	hh:mm	Days	in.	in.	in.	in.	%	psig	scfh	scfh	gallons	%	gallons	%
15-Oct-12	13:00	221	69	93.5	72	47.5	35.5%	13.6	7.7	7.9	43.9	7.0	44.2	7.3
17-Oct-12	11:00	223	69	93	72	48	34.8%	13.6	7.7	7.9	19.7	7.0	19.7	7.3
17-Oct-12	12:00	223	69	93.5	72	47.5	35.5%	13.6	7.7	7.9	44.7	8.0	46.1	7.3
19-Oct-12	8:00	225	69	93.5	72	47.5	35.5%	13.6	7.7	7.9	16.3	8.0	21.1	7.3
19-Oct-12	11:50	225	69	93.5	72	47.5	35.5%	13.6	7.7	7.9	47.4	8.0	47.4	7.3
22-Oct-12	10:10	228	69	93	72	48	34.8%	13.6	7.7	7.9	1.6	8.0	6.6	7.3
22-Oct-12	12:30	228	69	93.5	72	47.5	35.5%	13.6	7.6	7.9	46.1	8.0	47.4	7.3
24-Oct-12	12:00	230	69	92.5	72	48.5	34.1%	13.6	7.7	7.9	15.3	8.0	19.7	7.3
25-Oct-12	8:15	231	69	92.5	72	48.5	34.1%	13.6	7.5	8.1	1.3	8.0	7.9	7.3
25-Oct-12	11:15	231	69	93	72	48	34.8%	13.6	7.5	8.1	46.1	8.0	46.1	7.3
27-Oct-12	14:45	233	69	93	72	48	34.8%	13.6	7.5	8.1	46.1	8.0	46.1	7.3
29-Oct-12	11:00	235	69	92.5	72	48.5	34.1%	13.6	7.5	8.1	17.1	8.0	38.2	7.3
29-Oct-12	12:30	235	69	93	72	48	34.8%	13.6	7.5	8.1	46.1	8.0	37.9	7.3
31-Oct-12	8:35	237	69	92.5	72	48.5	34.1%	13.6	7.5	8.1	19.7	8.0	36.8	7.3
31-Oct-12	12:45	237	69	93	72	48	34.8%	13.6	7.5	8.1	46.1	8.0	35.5	7.3
2-Nov-12	7:45	239	69	92.5	72	48.5	34.1%	13.6	7.5	8.1	15.8	8.0	6.6	7.3
2-Nov-12	11:40	239	69	93	72	48	34.8%	13.6	7.5	8.1	46.8	8.0	46.8	7.3
5-Nov-12	10:15	242	69	93	72	48	34.8%	13.6	7.5	8.1	1.3	8.0	1.6	7.3
5-Nov-12	12:15	242	69	93	72	48	34.8%	13.6	7.5	8.1	46.8	8.0	47.1	7.3
7-Nov-12	9:00	244	69	92.5	72	48.5	34.1%	13.6	7.5	8.1	16.1	8.0	19.7	7.3
7-Nov-12	2:00	244	69	92.5	72	48.5	34.1%	13.6	7.5	8.1	43.4	8.0	44.7	7.3
9-Nov-12	8:30	246	69	92.5	72	48.5	34.1%	13.6	7.5	8.1	17.1	8.0	18.4	7.3
9-Nov-12	11:20	246	69	93	72	48	34.8%	13.6	7.5	8.1	46.8	8.0	47.1	7.3
12-Nov-12	8:00	249	69	92.5	72	48.5	34.1%	13.6	7.5	8.1	1.3	8.0	3.9	7.3

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR														
Date	Time	Elapsed Time	Settled Bed Height	FBR Bed Height	Settled Bed Depth from Top of vessel	Fluidized Bed Depth from Top of vessel	Percent Fluidization	Sweep Air /Biomass Separator Air Pressure (PRV-185)	Biomass Separator Flow Rate FI-185	Sweep Air Flow Rate FI-186	Nutrient Tank Feed Tank Volume T-106 (urea)	Nutrient Feed Pump Speed P-106(urea)	Nutrient Tank Feed Tank Volume T-107 (DAP)	Nutrient Feed Pump Speed P-107 (DAP)
d/m/y	hh:mm	Days	in.	in.	in.	in.	%	psig	scfh	scfh	gallons	%	gallons	%
12-Nov-12	13:30	249	69	92.5	72	48.5	34.1%	13.6	7.5	8.1	43.4	8.0	43.4	7.3
14-Nov-12	10:45	251	69	92.75	72	48.25	34.4%	13.6	7.5	8.1	14.5	8.0	16.3	7.3
14-Nov-12	12:30	251	69	92.75	72	48.25	34.4%	13.6	7.5	8.1	47.4	8.0	47.4	7.3
16-Nov-12	8:50	253	69	93	72	48	34.8%	13.6	7.5	7.7	17.1	8.0	19.7	7.3
16-Nov-12	10:50	253	69	93	72	48	34.8%	13.6	7.5	7.7	47.4	8.0	47.4	7.3
19-Nov-12	10:40	256	69	93	72	48	34.8%	13.6	7.5	7.7	1.3	8.0	5.3	7.3
19-Nov-12	12:25	256	69	93	72	48	34.8%	13.6	7.5	7.7	47.4	8.0	47.4	7.3
21-Nov-12	7:30	258	69	92.5	72	48.5	34.1%	13.6	7.5	7.7	17.1	8.0	21.1	7.3
21-Nov-12	10:30	258	69	92.75	72	48.25	34.4%	13.6	7.5	7.7	47.1	8.0	46.8	7.3
24-Nov-12	15:35	261	69	92.75	72	48.25	34.4%	13.6	7.5	7.7	46.8	8.0	47.4	7.3
26-Nov-12	9:30	263	69	92.75	72	48.25	34.4%	13.6	7.5	7.7	17.1	8.0	21.1	7.3
26-Nov-12	11:30	263	69	92.75	72	48.25	34.4%	13.6	7.5	7.7	47.4	8.0	47.4	7.3
28-Nov-12	10:15	265	69	92.5	72	48.5	34.1%	13.6	7.4	7.6	17.1	8.0	19.7	7.3
28-Nov-12	12:05	265	69	92.5	72	48.5	34.1%	13.6	7.4	7.6	47.4	8.0	47.4	7.3
30-Nov-12	8:50	267	69	93	72	48	34.8%	13.6	7.4	7.6	19.7	8.0	21.6	7.3
30-Nov-12	12:00	267	69	93	72	48	34.8%	13.6	7.4	7.6	46.8	8.0	47.4	7.3
3-Dec-12	7:50	270	69	92.5	72	48.5	34.1%	13.6	7.4	7.7	2.6	8.0	6.6	7.3
3-Dec-12	12:30	270	69	92	72	49	33.3%	13.6	7.4	7.7	46.1	OFF	46.1	OFF
5-Dec-12	11:00	272	69	90.5	72	50.5	31.2%	13.6	7.4	7.7	46.1	OFF	46.1	OFF
8-Dec-12	11:15	275	69	90	72	51	30.4%	13.6	7.4	7.7	46.1	OFF	46.1	OFF
10-Dec-12	11:00	277	69	89	72	52	29.0%	13.6	7.5	7.8	46.1	OFF	46.1	OFF
12-Dec-12	10:30	279	69	89	72	52	29.0%	13.6	7.5	7.8	46.1	OFF	46.1	OFF
12-Dec-12	12:15	279	69	89	72	52	29.0%	13.6	7.5	7.8	43.4	8.0	43.4	7.3
14-Dec-12	7:00	281	69	89	72	52	29.0%	13.6	7.5	7.8	15.8	8.0	18.4	7.3

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR														
Date	Time	Elapsed Time	Settled Bed Height	FBR Bed Height	Settled Bed Depth from Top of vessel	Fluidized Bed Depth from Top of vessel	Percent Fluidization	Sweep Air /Biomass Separator Air Pressure (PRV-185)	Biomass Separator Flow Rate FI-185	Sweep Air Flow Rate FI-186	Nutrient Tank Feed Tank Volume T-106 (urea)	Nutrient Feed Pump Speed P-106(urea)	Nutrient Tank Feed Tank Volume T-107 (DAP)	Nutrient Feed Pump Speed P-107 (DAP)
d/m/y	hh:mm	Days	in.	in.	in.	in.	%	psig	scfh	scfh	gallons	%	gallons	%
14-Dec-12	9:20	281	69	89	72	52	29.0%	13.6	7.5	7.8	47.4	8.0	47.4	7.3
17-Dec-12	12:25	284	69	89	72	52	29.0%	13.6	7.5	7.7	0.0	8.0	1.3	7.3
17-Dec-12	2:05	284	69	89	72	52	29.0%	13.6	7.5	7.7	46.8	8.0	46.8	7.3
19-Dec-12	9:20	286	69	89.5	72	51.5	29.7%	13.6	7.5	7.7	20.5	8.0	21.1	7.3
19-Dec-12	1:50	286	69	89.5	72	51.5	29.7%	13.6	7.5	7.7	17.1	8.0	19.7	7.3
20-Dec-12	8:45	287	69	89	72	52	29.0%	13.6	7.5	7.7	5.3	OFF	9.2	OFF
2-Jan-13	9:30	300	69	89	72	52	29.0%	13.8	6.2	7.8	46.1	OFF	46.1	OFF
2-Jan-13	11:45	300	69	89	72	52	29.0%	13.8	6.2	7.8	46.1	OFF	46.1	OFF
3-Jan-13	8:30	301	69	89	72	52	29.0%	13.8	6.2	7.9	46.1	OFF	46.1	OFF
7-Jan-13	8:45	305	69	88.75	72	52.25	28.6%	13.8	6.5	7.9	46.1	OFF	46.1	OFF
9-Jan-13	12:45	307	69	88.5	72	52.5	28.3%	13.8	6.2	8.0	46.1	OFF	46.1	OFF
9-Jan-13	2:40	307	69	88.5	72	52.5	28.3%	13.8	6.2	8.0	46.1	OFF	46.1	OFF
11-Jan-13	8:45	309	69	88.5	72	52.5	28.3%	13.8	6.2	8.0	46.1	OFF	46.1	OFF
14-Jan-13	8:15	312	69	89	72	52	29.0%	13.8	6.2	8.0	46.1	OFF	46.1	OFF
14-Jan-13	10:00	312	69	89	72	52	29.0%	13.8	6.2	8.0	46.1	OFF	46.1	OFF
16-Jan-13	9:15	314	69	89	72	52	29.0%	13.8	6.2	8.0	46.1	OFF	46.1	OFF
17-Jan-13	3:15	315	69	89	72	52	29.0%	14.0	6.5	7.6	46.1	OFF	46.1	OFF
17-Jan-13	5:30	315	69	89	72	52	29.0%	13.8	6.5	7.7	44.7	8.0	44.7	7.3
18-Jan-13	11:45	316	69	90	72	51	30.4%	13.8	6.5	7.7	39.5	8.0	40.0	7.3
20-Jan-13	1:30	318	69	90	72	51	30.4%	13.6	6.5	6.6	47.4	8.0	44.7	7.3
22-Jan-13	7:00	320	69	90	72	51	30.4%	13.6	6.5	6.6	20.5	8.0	18.4	7.3
22-Jan-13	11:30	320	69	90	72	51	30.4%	13.6	6.5	6.6	46.1	8.0	46.1	7.3
24-Jan-13	11:00	322	69	90	72	51	30.4%	13.6	6.2	6.8	14.5	8.0	15.8	7.3
25-Jan-13	8:00	323	69	90.25	72	50.75	30.8%	13.6	7.0	7.0	0.5	8.0	2.6	7.3

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR														
Date	Time	Elapsed Time	Settled Bed Height	FBR Bed Height	Settled Bed Depth from Top of vessel	Fluidized Bed Depth from Top of vessel	Percent Fluidization	Sweep Air /Biomass Separator Air Pressure (PRV-	Biomass Separator Flow Rate FI-185	Sweep Air Flow Rate FI-186	Nutrient Tank Feed Tank Volume T-106 (urea)	Nutrient Feed Pump Speed P-106(urea)	Nutrient Tank Feed Tank Volume T-107 (DAP)	Nutrient Feed Pump Speed P-107 (DAP)
d/m/y	hh:mm	Days	in.	in.	in.	in.	%	psig	scfh	scfh	gallons	%	gallons	%
25-Jan-13	10:00	323	69	90.25	72	50.75	30.8%	13.6	7.0	7.0	46.1	8.0	46.8	7.3
28-Jan-13	10:15	326	69	90.5	72	50.5	31.2%	13.2	6.2	6.6	0.3	8.0	2.9	7.3
28-Jan-13	12:20	326	69	90.5	72	50.5	31.2%	13.4	6.8	7.1	46.1	8.0	46.8	7.3
30-Jan-13	10:30	328	69	90	72	51	30.4%	13.4	6.4	7.1	16.3	8.0	18.4	7.3
30-Jan-13	12:30	328	69	90	72	51	30.4%	13.4	6.2	7.2	47.4	8.0	46.1	7.3
1-Feb-13	8:20	330	69	90	72	51	30.4%	14.0	5.0	6.5	22.4	8.0	21.1	7.3
1-Feb-13	10:40	330	69	90	72	51	30.4%	14.0	5.0	6.5	47.4	8.0	47.4	7.3
4-Feb-13	9:10	333	69	90	72	51	30.4%	13.8	4.5	6.2	0.5	8.0	3.2	7.3
4-Feb-13	11:40	333	69	90	72	51	30.4%	13.8	4.5	6.2	46.1	8.0	46.1	7.3
7-Feb-13	7:50	336	69	90	72	51	30.4%	13.6	6.5	7.2	2.6	8.0	5.8	7.3
7-Feb-13	11:30	336	69	90	72	51	30.4%	13.6	6.5	7.2	46.1	8.0	47.4	7.3
8-Feb-13	10:30	337	69	90.25	72	50.75	30.8%	13.8	6.5	7.5	42.1	8.0	43.4	7.3
20-Feb-13	11:00	349	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
25-Feb-13	15:15	354	69	89	72	52	29.0%	13.2	7.5	7.7	31.6	8.0	32.1	7.3
27-Feb-13	11:35	356	69	88.5	72	52.5	28.3%	13.4	8.0	8.5	44.7	8.0	42.1	7.3
28-Feb-13	10:00	357	69	88.75	72	52.25	28.6%	13.4	7.0	8.0	31.6	8.0	27.6	7.3
28-Feb-13	12:30	357	69	88.75	72	52.25	28.6%	13.4	7.0	8.0	16.3	8.0	14.5	7.3
4-Mar-13	11:30	361	69	88.5	72	52.5	28.3%	13.4	7.0	8.0	46.1	8.0	46.1	7.3
6-Mar-13	7:40	363	69	89	72	52	29.0%	13.6	7.0	7.3	46.1	8.0	46.1	7.3
6-Mar-13	10:20	363	69	89	72	52	29.0%	13.8	7.1	7.4	15.8	8.0	17.1	7.3
8-Mar-13	8:30	365	69	89	72	52	29.0%	13.8	7.1	7.4	47.4	8.0	48.7	7.3
8-Mar-13	10:15	365	69	89.25	72	51.75	29.3%	13.6	7.0	7.4	17.1	8.0	22.4	7.3
11-Mar-13	10:15	368	69	89.25	72	51.75	29.3%	13.6	6.9	7.5	47.4	8.0	47.4	7.3
11-Mar-13	12:15	368	69	89	72	52	29.0%	14.0	5.0	7.0	27.6	8.0	30.3	7.3

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR														
Date	Time	Elapsed Time	Settled Bed Height	FBR Bed Height	Settled Bed Depth from Top of vessel	Fluidized Bed Depth from Top of vessel	Percent Fluidization	Sweep Air /Biomass Separator Air Pressure (PRV-185)	Biomass Separator Flow Rate FI-185	Sweep Air Flow Rate FI-186	Nutrient Tank Feed Tank Volume T-106 (urea)	Nutrient Feed Pump Speed P-106(urea)	Nutrient Tank Feed Tank Volume T-107 (DAP)	Nutrient Feed Pump Speed P-107 (DAP)
d/m/y	hh:mm	Days	inches	inches	in.	in.	%	psig	scfh	scfh	gallons	%	gallons	%
13-Mar-13	1:15	370	69	88.5	72	52.5	0.28261	14.0	5.0	7.5	44.7	8.0	46.1	7.3
14-Mar-13	9:52	371	69	88	72	53	0.27536	14.0	5.0	6.0	28.9	8.0	31.6	7.3
15-Mar-13	7:30	372	69	88	72	53	0.27536	14.0	5.0	6.0	15.8	8.0	19.7	7.3
15-Mar-13	10:45	372	69	88	72	53	0.27536	14.0	5.0	6.0	46.1	8.0	46.8	7.3
18-Mar-13	9:45	375	69	88	72	53	0.27536	14.0	5.0	6.0	1.3	8.0	3.9	7.3
18-Mar-13	12:00	375	69	88	72	53	0.27536	13.8	4.5	6.2	42.1	8.5	43.4	8.0
20-Mar-13	6:30	377	69	87.75	72	53.25	0.27174	13.8	4.5	6.2	10.5	8.5	13.2	8.0

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR												
Date	Time	Elapsed Time	Oxygen Mass Feed Flow FT-103	Oxygen Volumetric Feed Flow FI-103	Oxygen Tank Pressure T-120 PI	Oxygen Feed Pressure T-120 PI	Oxygen Feed Mode	Oxygen Proportionality Constant KO1	Oxygen Sensitivity Constant KO2	Oxygen Feed Constant KO3	Oxygen Time Interval TO1	Dissolved Oxygen Set Point DO_{SP}
d/m/y	hh:mm	Days	mg/min	milli-meter	psig	psig					min	mg/L
8-Mar-12	9:02	0	0.0	0.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
12-Mar-12	8:27	4	0.0	0.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
12-Mar-12	11:00	4	0.0	0.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
14-Mar-12	8:28	6	0.0	0.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
16-Mar-12	9:30	8	0.0	0.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
19-Mar-12	10:00	11	0.0	0.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
21-Mar-12	8:05	13	0.0	0.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
23-Mar-12	12:00	15	0.0	0.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
26-Mar-12	15:30	18	0.0	0.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
27-Mar-12	8:00	19	0.0	0.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
27-Mar-12	11:33	19	0.0	0.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
30-Mar-12	12:45	22	0.0	0.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2-Apr-12	16:00	25	0.0	0.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
4-Apr-12	8:00	27	0.0	0.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
5-Apr-12	9:30	28	0.0	0.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
10-Apr-12	9:15	33	0.0	0.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
16-Apr-12	13:30	39	0.0	0.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
18-Apr-12	12:30	41	0.0	0.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
19-Apr-12	10:30	42	0.0	0.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
24-Apr-12	9:08	47	0.0	0.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
26-Apr-12	12:00	49	0.0	0.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
30-Apr-12	10:15	53	0.0	0.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
30-Apr-12	14:00	53	0.0	0.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
30-Apr-12	15:00	53	0.0	0.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR

Date	Time	Elapsed Time	Oxygen Mass Feed Flow FT-103	Oxygen Volumetric Feed Flow FI-103	Oxygen Tank Pressure T-120 PI	Oxygen Feed Pressure T-120 PI	Oxygen Feed Mode	Oxygen Proportionality Constant KO1	Oxygen Sensitivity Constant KO2	Oxygen Feed Constant KO3	Oxygen Time Interval TO1	Dissolved Oxygen Set Point DO_{SP}
d/m/y	hh:mm	Days	mg/min	millimeter	psig	psig					min	mg/L
1-May-12	15:30	54	0.0	0.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3-May-12	11:15	56	0.0	0.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3-May-12	12:00	56	0.0	0.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3-May-12	13:30	56	0.0	0.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
7-May-12	11:15	60	0.0	0.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
10-May-12	16:45	63	0.0	0.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
14-May-12	8:15	67	0.0	0.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
14-May-12	12:15	67	0.0	0.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
15-May-12	15:00	68	0.0	0.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
21-May-12	14:15	74	0.0	7.0	2600.0	30.0	feed	0.01	0.01	0.1	5.0	7.0
22-May-12	16:00	75	2.0	0.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
23-May-12	12:30	76	0.0	0.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
25-May-12	12:00	78	0.0	0.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
29-May-12	12:50	82	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
30-May-12	13:05	83	0.0	0.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
30-May-12	14:50	83	38.0	0.0	2700.0	35.0	Time step	0.03	0.20	1.0	5.0	2.0
30-May-12	16:08	83	100.0	0.0	2700.0	35.0	Time step	0.10	0.01`	1.0	30.0	3.0
31-May-12	8:00	84	103.0	0.0	2400.0	35.0	Time step	0.10	0.01	1.0	30.0	3.0
31-May-12	9:15	84	101.0	0.0	2400.0	35.0	Time step	0.10	0.01	1.0	30.0	3.0
31-May-12	10:30	84	102.0	0.0	2400.0	35.0	Time step	0.10	0.01	1.0	30.0	3.0
31-May-12	11:45	84	98.0	0.0	2450.0	35.0	Time step	0.10	0.01	1.0	30.0	3.0
31-May-12	14:00	84	99.0	0.0	2450.0	35.0	Time step	0.10	0.01	1.0	30.0	3.0
31-May-12	14:30	84	99.0	0.0	2450.0	35.0	Time step	0.10	0.01	1.0	30.0	3.0
1-Jun-12	7:15	85	98.0	0.0	2300.0	35.0	Time step	0.10	0.01	1.0	30.0	3.0

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR

Date	Time	Elapsed Time	Oxygen Mass Feed Flow FT-103	Oxygen Volumetric Feed Flow FI-103	Oxygen Tank Pressure T-120 PI	Oxygen Feed Pressure T-120 PI	Oxygen Feed Mode	Oxygen Proportionality Constant KO1	Oxygen Sensitivity Constant KO2	Oxygen Feed Constant KO3	Oxygen Time Interval TO1	Dissolved Oxygen Set Point DO_{SP}
d/m/y	hh:mm	Days	mg/min	milli-meter	psig	psig					min	mg/L
1-Jun-12	10:00	85	96.0	0.0	2350.0	34.0	Time step	0.10	0.01	1.0	30.0	3.0
1-Jun-12	12:00	85	94.0	0.0	2400.0	34.0	Time step	0.09	0.01	1.0	30.0	3.0
2-Jun-12	9:00	86	100.0	0.0	2300.0	34.0	Time step	0.10	0.01	1.0	30.0	3.0
2-Jun-12	10:30	86	98.0	0.0	2300.0	34.0	Time step	0.10	0.01	1.0	30.0	3.0
2-Jun-12	11:30	86	99.0	0.0	2300.0	34.0	Time step	0.10	0.01	1.0	30.0	3.0
2-Jun-12	12:30	86	102.0	0.0	2400.0	35.0	Time step	0.10	0.01	1.0	30.0	3.0
4-Jun-12	8:30	88	100.0	0.0	2200.0	34.0	Time step	0.10	0.01	1.0	30.0	3.0
4-Jun-12	13:30	88	97.0	0.0	2300.0	34.0	Time step	0.10	0.01	1.0	30.0	3.0
5-Jun-12	14:30	89	97.0	0.0	2200.0	35.0	Time step	0.10	0.01	1.0	30.0	3.0
6-Jun-12	9:00	90	102.0	0.0	2100.0	35.0	Time step	0.10	0.01	1.0	30.0	3.0
6-Jun-12	13:07	90	373.0	6.0	2250.0	35.0	Feed Flow	0.53	0.01	1.0	30.0	3.0
6-Jun-12	15:40	90	336.0	6.0	2000.0	35.0	Feed Flow	0.48	0.01	1.0	30.0	3.0
7-Jun-12	8:05	91	191.0	0.0	2000.0	35.0	Feed Flow	0.27	0.01	1.0	30.0	3.0
7-Jun-12	10:40	91	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
7-Jun-12	12:00	91	184.0	0.0	2100.0	35.0	Feed Flow	0.23	0.01	1.0	30.0	3.0
7-Jun-12	13:20	91	196.0	0.0	2100.0	35.0	Feed Flow	0.28	0.01	1.0	30.0	3.0
8-Jun-12	8:00	92	197.0	0.0	1900.0	35.0	Feed Flow	0.28	0.01	1.0	30.0	3.0
8-Jun-12	10:30	92	197.0	0.0	1900.0	35.0	Feed Flow	0.28	0.01	1.0	30.0	3.0
8-Jun-12	12:15	92	196.0	0.0	2000.0	35.0	Feed Flow	0.28	0.01	1.0	30.0	3.0
8-Jun-12	13:00	92	197.0	0.0	2000.0	35.0	Feed Flow	0.28	0.01	1.0	30.0	3.0
8-Jun-12	14:00	92	196.0	0.0	2000.0	35.0	Feed Flow	0.28	0.01	1.0	30.0	3.0
9-Jun-12	10:40	93	197.0	0.0	1900.0	35.0	Feed Flow	0.28	0.01	1.0	30.0	3.0
9-Jun-12	12:00	93	272.0	0.0	1950.0	35.0	Feed Flow	0.34	0.01	1.0	30.0	3.0

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR

Date	Time	Elapsed Time	Oxygen Mass Feed Flow FT-103	Oxygen Volumetric Feed Flow FI-103	Oxygen Tank Pressure T-120 PI	Oxygen Feed Pressure T-120 PI	Oxygen Feed Mode	Oxygen Proportionality Constant KO1	Oxygen Sensitivity Constant KO2	Oxygen Feed Constant KO3	Oxygen Time Interval TO1	Dissolved Oxygen Set Point DO_{SP}
d/m/y	hh:mm	Days	mg/min	milli-meter	psig	psig					min	mg/L
9-Jun-12	13:00	93	239.0	0.0	1950.0	35.0	Feed Flow	0.34	0.01	1.0	30.0	3.0
9-Jun-12	14:00	93	252.0	0.0	1950.0	35.0	Feed Flow	0.36	0.01	1.0	30.0	3.0
9-Jun-12	15:00	93	242.0	0.0	1950.0	35.0	Feed Flow	0.34	0.01	1.0	30.0	3.0
11-Jun-12	7:50	95	239.0	0.0	1700.0	35.0	Feed Flow	0.34	0.01	1.0	30.0	3.0
11-Jun-12	11:30	95	280.0	0.0	1750.0	35.0	Feed Flow	0.40	0.01	1.0	30.0	3.0
11-Jun-12	13:00	95	282.0	0.0	1750.0	35.0	Feed Flow	0.40	0.01	1.0	30.0	3.0
11-Jun-12	14:00	95	294.0	0.0	1750.0	35.0	Feed Flow	0.42	0.01	1.0	30.0	3.0
13-Jun-12	8:00	97	294.0	0.0	1500.0	34.0	Feed Flow	0.42	0.01	1.0	30.0	3.0
13-Jun-12	13:40	97	258.0	0.0	1600.0	34.0	Feed Flow	0.42	0.01	1.0	30.0	3.0
13-Jun-12	15:00	97	294.0	0.0	1600.0	34.0	Feed Flow	0.42	0.01	1.0	30.0	3.0
14-Jun-12	8:30	98	294.0	0.0	1400.0	34.0	Feed Flow	0.42	0.01	1.0	30.0	3.0
14-Jun-12	9:00	98	295.0	0.0	1400.0	34.0	Feed Flow	0.42	0.01	1.0	30.0	3.0
14-Jun-12	11:00	98	295.0	0.0	1350.0	34.0	Feed Flow	0.42	0.01	1.0	30.0	3.0
15-Jun-12	8:00	99	268.0	0.0	1300.0	34.0	Feed Flow	0.38	0.01	1.0	30.0	3.0
15-Jun-12	12:15	99	268.0	0.0	1350.0	34.0	Feed Flow	0.38	0.01	1.0	30.0	3.0
16-Jun-12	22:00	100	269.0	0.0	1250.0	34.0	Feed Flow	0.38	0.01	1.0	30.0	3.0
18-Jun-12	11:00	102	304.0	0.0	1100.0	34.0	Feed Flow	0.38	0.01	1.0	30.0	3.0
20-Jun-12	10:00	104	268.0	0.0	900.0	34.0	Feed Flow	0.38	0.01	1.0	30.0	3.0
20-Jun-12	12:20	104	304.0	0.0	900.0	34.0	Feed Flow	0.38	0.01	1.0	30.0	3.0
22-Jun-12	9:00	106	266.0	0.0	700.0	34.0	Feed Flow	0.38	0.01	1.0	30.0	3.0
25-Jun-12	12:00	109	304.0	0.0	400.0	34.0	Feed Flow	0.38	0.01	1.0	30.0	3.0
27-Jun-12	9:00	111	304.0	0.0	200.0	34.0	Feed Flow	0.38	0.01	1.0	30.0	3.0
27-Jun-12	12:30	111	268.0	0.0	200.0	34.0	Feed Flow	0.38	0.01	1.0	30.0	3.0
28-Jun-12	10:25	112	305.0	3.0	2600.0	35.0	Feed Flow	0.32	0.01	1.0	30.0	3.0

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR												
Date	Time	Elapsed Time	Oxygen Mass Feed Flow FT-103	Oxygen Volumetric Feed Flow FI-103	Oxygen Tank Pressure T-120 PI	Oxygen Feed Pressure T-120 PI	Oxygen Feed Mode	Oxygen Proportionality Constant KO1	Oxygen Sensitivity Constant KO2	Oxygen Feed Constant KO3	Oxygen Time Interval TO1	Dissolved Oxygen Set Point DO_{SP}
d/m/y	hh:mm	Days	mg/min	milli-meter	psig	psig					min	mg/L
2-Jul-12	11:15	116	371.0	4.0	2250.0	35.0	Feed Flow	0.34	0.5	1.0	30.0	3.0
3-Jul-12	8:45	117	300.0	2.0	2100.0	35.0	Feed Flow	0.28	0.5	1.0	30.0	3.0
5-Jul-12	9:30	119	261.0	0.0	1850.0	35.0	Feed Flow	0.26	0.5	1.0	30.0	3.0
7-Jul-12	17:45	121	264.0	0.0	1650.0	35.0	Feed Flow	0.26	0.5	1.0	30.0	3.0
9-Jul-12	12:15	123	288.0	0.0	1500.0	35.0	Feed Flow	0.26	0.5	1.0	30.0	3.0
11-Jul-12	10:40	125	264.0	0.0	1300.0	35.0	Feed Flow	0.24	0.5	1.0	30.0	3.0
12-Jul-12	8:15	126	242.0	0.0	1200.0	35.0	Feed Flow	0.24	0.5	1.0	30.0	3.0
12-Jul-12	11:45	126	242.0	0.0	1200.0	35.0	Feed Flow	0.24	0.5	1.0	30.0	3.0
16-Jul-12	12:00	130	264.0	0.0	850.0	35.0	Feed Flow	0.24	0.5	1.0	30.0	3.0
19-Jul-12	17:00	133	112.0	6.0	800.0	75.0	Feed Flow	0.10	0.5	1.0	30.0	3.0
20-Jul-12	11:15	134	150.0	0.0	650.0	76.0	Feed Flow	0.15	0.5	1.0	30.0	3.0
23-Jul-12	11:45	137	148.0	0.0	400.0	75.0	Time step	0.15	0.5	1.0	30.0	7.0
24-Jul-12	20:45	138	332.0	0.0	300.0	45.0	Feed Flow	0.30	0.5	1.0	30.0	5.0
25-Jul-12	12:15	139	100.0	0.0	2350.0	40.0	Time step	0.10	0.5	1.0	30.0	6.0
25-Jul-12	13:40	139	158.0	0.0	2350.0	40.0	Time step	0.16	0.5	1.0	30.0	6.0
26-Jul-12	13:00	140	146.0	0.0	2400.0	40.0	Time step	0.14	0.5	1.0	30.0	6.0
26-Jul-12	15:00	140	244.0	0.0	2400.0	40.0	Feed Flow	0.24	0.5	1.0	30.0	6.0
27-Jul-12	11:15	141	201.0	0.0	2250.0	40.0	Feed Flow	0.20	0.5	1.0	5.0	6.0
30-Jul-12	9:35	144	201.0	0.0	2100.0	40.0	Feed Flow	0.20	0.5	1.0	5.0	6.0
1-Aug-12	11:40	146	220.0	0.0	2000.0	40.0	Feed Flow	0.20	0.5	1.0	5.0	6.0
3-Aug-12	10:45	148	220.0	0.0	1850.0	40.0	Feed Flow	0.20	0.5	1.0	5.0	6.0
6-Aug-12	11:20	151	260.0	0.0	1700.0	40.0	Feed Flow	0.24	0.5	1.0	5.0	6.0
8-Aug-12	8:10	153	222.0	0.0	1510.0	40.0	Feed Flow	0.22	0.5	1.0	5.0	6.0
8-Aug-12	14:20	153	188.0	0.0	1500.0	40.0	Time step	0.19	0.5	1.0	5.0	6.0

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR												
Date	Time	Elapsed Time	Oxygen Mass Feed Flow FT-103	Oxygen Volumetric Feed Flow FI-103	Oxygen Tank Pressure T-120 PI	Oxygen Feed Pressure T-120 PI	Oxygen Feed Mode	Oxygen Proportionality Constant KO1	Oxygen Sensitivity Constant KO2	Oxygen Feed Constant KO3	Oxygen Time Interval TO1	Dissolved Oxygen Set Point DO_{SP}
d/m/y	hh:mm	Days	mg/min	milli-meter	psig	psig					min	mg/L
9-Aug-12	13:30	154	205.0	0.0	1500.0	40.0	Feed Flow	0.20	0.5	1.0	5.0	6.0
13-Aug-12	8:15	158	241.0	0.0	1250.0	40.0	Feed Flow	0.22	0.5	1.0	5.0	6.0
13-Aug-12	12:10	158	242.0	0.0	1250.0	40.0	Feed Flow	0.22	0.5	1.0	5.0	6.0
15-Aug-12	8:21	160	161.0	0.0	1100.0	40.0	Time step	0.16	0.5	1.0	5.0	6.0
15-Aug-12	11:00	160	246.0	0.0	1100.0	40.0	Feed Flow	0.20	0.5	1.0	5.0	6.0
16-Aug-12	12:00	161	264.0	0.0	1050.0	40.0	Feed Flow	0.22	0.5	1.0	5.0	6.0
20-Aug-12	10:45	165	242.0	0.0	750.0	40.0	Feed Flow	0.22	0.5	1.0	5.0	6.0
20-Aug-12	13:00	165	244.0	0.0	750.0	40.0	Feed Flow	0.16	0.5	1.0	5.0	6.0
22-Aug-12	11:00	167	240.0	0.0	600.0	40.0	Feed Flow	0.160	0.5	1.0	5.0	6.0
23-Aug-12	11:30	168	142.0	0.0	500.0	40.0	Time Step	0.140	0.5	1.0	5.0	5.0
23-Aug-12	17:00	168	224.0	0.0	500.0	40.0	Feed Flow	0.160	0.5	1.0	5.0	5.0
24-Aug-12	10:05	169	154.0	0.0	490.0	40.0	Time Step	0.150	0.5	1.0	5.0	5.0
24-Aug-12	11:30	169	218.0	0.0	490.0	40.0	Feed Flow	0.160	0.5	1.0	5.0	5.0
27-Aug-12	11:15	172	248.0	0.0	300.0	40.0	Feed Flow	0.160	0.5	1.0	5.0	5.0
29-Aug-12	8:30	174	115.0	0.0	150.0	40.0	Timestep	0.12	0.5	1.0	5.0	5.0
29-Aug-12	10:45	174	235.0	0.0	2300.0	40.0	Timestep	0.24	0.5	1.0	5.0	5.5
29-Aug-12	12:00	174	262.0	0.0	2300.0	40.0	Feed flow	0.16	0.5	1.0	5.0	5.5
30-Aug-12	7:50	175	197.0	0.0	2150.0	40.0	Feed flow	0.14	0.5	1.0	5.0	5.5
1-Sep-12	17:00	177	226.0	0.0	2250.0	40.0	Feed flow	0.16	0.5	1.0	10.0	5.0
2-Sep-12	11:30	178	131.0	0.0	2100.0	40.0	Time step	0.13	0.5	1.0	10.0	5.0
2-Sep-12	15:00	178	242.0	0.0	2100.0	40.0	Feed flow	0.16	0.5	1.0	10.0	5.0
5-Sep-12	12:45	181	242.0	0.0	1810.0	40.0	Feed flow	0.16	0.5	1.0	10.0	5.0
6-Sep-12	8:05	182	242.0	0.0	1650.0	40.0	Feed flow	0.16	0.5	1.0	10.0	5.0
10-Sep-12	11:00	186	224.0	0.0	1500.0	40.0	Feed flow	0.14	0.5	1.0	10.0	5.0

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR

Date	Time	Elapsed Time	Oxygen Mass Feed Flow FT-103	Oxygen Volumetric Feed Flow FI-103	Oxygen Tank Pressure T-120 PI	Oxygen Feed Pressure T-120 PI	Oxygen Feed Mode	Oxygen Proportionality Constant KO1	Oxygen Sensitivity Constant KO2	Oxygen Feed Constant KO3	Oxygen Time Interval TO1	Dissolved Oxygen Set Point DO_{SP}
d/m/y	hh:mm	Days	mg/min	milli-meter	psig	psig					min	mg/L
12-Sep-12	10:30	188	226.0	0.0	1350.0	40.0	Feed flow	0.16	0.5	1.0	10.0	5.0
12-Sep-12	11:00	188	226.0	0.0	1350.0	40.0	Feed flow	0.16	0.5	1.0	10.0	5.0
14-Sep-12	7:30	190	128.0	0.0	1200.0	40.0	Time Step	0.13	0.5	1.0	10.0	5.0
14-Sep-12	9:15	190	161.0	0.0	1200.0	40.0	Time Step	0.18	0.5	1.0	10.0	5.0
15-Sep-12	9:30	191	135.0	0.0	1190.0	40.0	Time step	0.14	0.5	1.0	10.0	5.0
15-Sep-12	11:10	191	273.0	0.0	1190.0	40.0	Time step	0.27	0.5	1.0	10.0	5.0
17-Sep-12	15:30	193	166.0	0.0	1150.0	40.0	Time step	0.17	0.5	1.0	10.0	5.0
17-Sep-12	17:30	193	182.0	0.0	1150.0	40.0	Time step	0.18	0.5	1.0	10.0	5.0
19-Sep-12	9:45	195	242.0	0.0	950.0	40.0	Feed Flow	0.14	0.5	1.0	10.0	5.0
20-Sep-12	9:35	196	210.0	0.0	900.0	40.0	Feed Flow	0.14	0.5	1.0	10.0	5.0
24-Sep-12	11:00	200	210.0	0.0	690.0	40.0	Feed Flow	0.14	0.5	1.0	10.0	5.0
26-Sep-12	10:30	202	226.0	0.0	550.0	40.0	Feed Flow	0.14	0.5	1.0	10.0	5.0
28-Sep-12	9:20	204	228.0	0.0	400.0	40.0	Feed Flow	0.11	0.5	1.0	10.0	5.0
29-Sep-12	11:00	205	258.0	0.0	390.0	40.0	Feed Flow	0.11	0.5	1.0	10.0	5.0
1-Oct-12	9:45	207	230.0	0.0	200.0	40.0	Feed Flow	0.10	0.5	1.0	10.0	5.0
2-Oct-12	10:35	208	220.0	0.0	130.0	40.0	Feed Flow	0.10	0.5	1.0	10.0	5.0
3-Oct-12	9:00	209	230.0	0.0	1900.0	40.0	Feed Flow	0.10	0.5	1.0	10.0	5.0
3-Oct-12	11:00	209	220.0	0.0	1900.0	40.0	Feed Flow	0.10	0.5	1.0	10.0	5.0
4-Oct-12	9:30	210	220.0	0.0	1800.0	40.0	Feed Flow	0.10	0.5	1.0	10.0	5.0
8-Oct-12	9:00	214	220.0	0.0	1550.0	40.0	Feed Flow	0.10	0.5	1.0	10.0	5.0
9-Oct-12	15:00	215	248.0	0.0	1600.0	40.0	Feed Flow	0.11	0.5	1.0	10.0	5.0
10-Oct-12	11:45	216	177.0	0.0	1450.0	40.0	Feed Flow	0.08	0.5	1.0	10.0	5.0
11-Oct-12	12:00	217	168.0	0.0	1390.0	40.0	Feed Flow	0.08	0.5	1.0	10.0	5.0
15-Oct-12	12:00	221	176.0	0.0	1150.0	40.0	Feed Flow	0.08	0.5	1.0	10.0	5.0

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR

Date	Time	Elapsed Time	Oxygen Mass Feed Flow FT-103	Oxygen Volumetric Feed Flow FI-103	Oxygen Tank Pressure T-120 PI	Oxygen Feed Pressure T-120 PI	Oxygen Feed Mode	Oxygen Proportionality Constant KO1	Oxygen Sensitivity Constant KO2	Oxygen Feed Constant KO3	Oxygen Time Interval TO1	Dissolved Oxygen Set Point DO_{SP}
d/m/y	hh:mm	Days	mg/min	milli-meter	psig	psig					min	mg/L
15-Oct-12	13:00	221	176.0	0.0	1150.0	40.0	Feed Flow	0.08	0.5	1.0	10.0	5.0
17-Oct-12	11:00	223	176.0	0.0	1050.0	40.0	Feed Flow	0.08	0.5	1.0	10.0	5.0
17-Oct-12	12:00	223	176.0	0.0	1050.0	40.0	Feed Flow	0.08	0.5	1.0	10.0	5.0
19-Oct-12	8:00	225	170.0	0.0	900.0	40.0	Feed Flow	0.08	0.5	1.0	10.0	5.0
19-Oct-12	11:50	225	176.0	0.0	900.0	40.0	Feed Flow	0.08	0.5	1.0	10.0	5.0
22-Oct-12	10:10	228	176.0	0.0	790.0	40.0	Feed Flow	0.08	0.5	1.0	10.0	5.0
22-Oct-12	12:30	228	176.0	0.0	790.0	40.0	Feed Flow	0.08	0.5	1.0	10.0	5.0
24-Oct-12	12:00	230	178.0	0.0	690.0	40.0	Feed Flow	0.08	0.5	1.0	10.0	5.0
25-Oct-12	8:15	231	176.0	0.0	610.0	40.0	Feed Flow	0.08	0.5	1.0	10.0	5.0
25-Oct-12	11:15	231	178.0	0.0	600.0	40.0	Feed Flow	0.08	0.5	1.0	10.0	5.0
27-Oct-12	14:45	233	178.0	0.0	500.0	40.0	Feed Flow	0.08	0.5	1.0	10.0	5.0
29-Oct-12	11:00	235	176.0	0.0	400.0	40.0	Feed Flow	0.08	0.5	1.0	10.0	5.0
29-Oct-12	12:30	235	168.0	0.0	400.0	40.0	Feed Flow	0.08	0.5	1.0	10.0	5.0
31-Oct-12	8:35	237	170.0	0.0	290.0	40.0	Feed Flow	0.08	0.5	1.0	10.0	5.0
31-Oct-12	12:45	237	177.0	0.0	290.0	40.0	Feed Flow	0.08	0.5	1.0	10.0	5.0
2-Nov-12	7:45	239	178.0	0.0	160.0	40.0	Feed Flow	0.08	0.5	1.0	10.0	5.0
2-Nov-12	11:40	239	171.0	0.0	2050.0	40.0	Feed Flow	0.04	0.5	1.0	10.0	5.0
5-Nov-12	10:15	242	178.0	0.0	1850.0	40.0	Feed Flow	0.04	0.5	1.0	10.0	5.0
5-Nov-12	12:15	242	172.0	0.0	1850.0	40.0	Feed Flow	0.04	0.5	1.0	10.0	5.0
7-Nov-12	9:00	244	176.0	0.0	1750.0	40.0	Feed Flow	0.04	0.5	1.0	10.0	5.0
7-Nov-12	2:00	244	175.0	0.0	1750.0	40.0	Feed Flow	0.04	0.5	1.0	10.0	5.0
9-Nov-12	8:30	246	176.0	0.0	1700.0	40.0	Feed Flow	0.04	0.5	1.0	10.0	5.0
9-Nov-12	11:20	246	175.0	0.0	1700.0	40.0	Feed Flow	0.04	0.5	1.0	10.0	5.0
12-Nov-12	8:00	249	180.0	0.0	1450.0	40.0	Feed Flow	0.04	0.5	1.0	10.0	5.0

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR												
Date	Time	Elapsed Time	Oxygen Mass Feed Flow FT-103	Oxygen Volumetric Feed Flow FI-103	Oxygen Tank Pressure T-120 PI	Oxygen Feed Pressure T-120 PI	Oxygen Feed Mode	Oxygen Proportionality Constant KO1	Oxygen Sensitivity Constant KO2	Oxygen Feed Constant KO3	Oxygen Time Interval TO1	Dissolved Oxygen Set Point DO_{SP}
d/m/y	hh:mm	Days	mg/min	milli-meter	psig	psig					min	mg/L
12-Nov-12	13:30	249	130.0	0.0	1450.0	40.0	Feed Flow	0.03	0.5	1.0	10.0	5.0
14-Nov-12	10:45	251	130.0	0.0	1400.0	40.0	Feed Flow	0.03	0.5	1.0	10.0	5.0
14-Nov-12	12:30	251	130.0	0.0	1400.0	40.0	Feed Flow	0.03	0.5	1.0	10.0	5.0
16-Nov-12	8:50	253	132.0	0.0	1350.0	40.0	Feed Flow	0.03	0.5	1.0	10.0	5.0
16-Nov-12	10:50	253	133.0	0.0	1350.0	40.0	Feed Flow	0.03	0.5	1.0	10.0	5.0
19-Nov-12	10:40	256	130.0	0.0	1200.0	40.0	Feed Flow	0.03	0.5	1.0	10.0	5.0
19-Nov-12	12:25	256	133.0	0.0	1200.0	40.0	Feed Flow	0.03	0.5	1.0	10.0	5.0
21-Nov-12	7:30	258	128.0	0.0	1190.0	40.0	Feed Flow	0.03	0.5	1.0	10.0	5.0
21-Nov-12	10:30	258	131.0	0.0	1190.0	40.0	Feed Flow	0.03	0.5	1.0	10.0	5.0
24-Nov-12	15:35	261	130.0	0.0	1100.0	40.0	Feed Flow	0.03	0.5	1.0	10.0	5.0
26-Nov-12	9:30	263	129.0	0.0	1000.0	40.0	Feed Flow	0.03	0.5	1.0	10.0	5.0
26-Nov-12	11:30	263	130.0	0.0	1000.0	40.0	Feed Flow	0.03	0.5	1.0	10.0	5.0
28-Nov-12	10:15	265	131.0	0.0	900.0	40.0	Feed Flow	0.03	0.5	1.0	10.0	5.0
28-Nov-12	12:05	265	128.0	0.0	900.0	40.0	Feed Flow	0.03	0.5	1.0	10.0	5.0
30-Nov-12	8:50	267	130.0	0.0	850.0	40.0	Feed Flow	0.03	0.5	1.0	10.0	5.0
30-Nov-12	12:00	267	158.0	0.0	850.0	40.0	Feed Flow	0.04	0.5	1.0	10.0	5.0
3-Dec-12	7:50	270	172.0	0.0	700.0	40.0	Feed Flow	0.04	0.5	1.0	10.0	5.0
3-Dec-12	12:30	270	88.0	0.0	700.0	40.0	Feed Flow	0.02	0.5	1.0	10.0	5.0
5-Dec-12	11:00	272	11.0	0.0	620.0	40.0	Time step	0.0	0.5	1.0	10.0	5.0
8-Dec-12	11:15	275	36.0	0.0	600.0	40.0	Time step	0.02	0.5	1.0	10.0	5.0
10-Dec-12	11:00	277	12.0	0.0	600.0	40.0	Time step	0.00	0.5	1.0	10.0	5.0
12-Dec-12	10:30	279	12.0	0.0	570.0	40.0	Time step	0.00	0.5	1.0	10.0	5.0
12-Dec-12	12:15	279	130.0	0.0	570.0	40.0	Feed Flow	0.03	0.5	1.0	10.0	5.0
14-Dec-12	7:00	281	130.0	0.0	550.0	40.0	Feed Flow	0.03	0.5	1.0	10.0	5.0

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR

Date	Time	Elapsed Time	Oxygen Mass Feed Flow FT-103	Oxygen Volumetric Feed Flow FI-103	Oxygen Tank Pressure T-120 PI	Oxygen Feed Pressure T-120 PI	Oxygen Feed Mode	Oxygen Proportionality Constant KO1	Oxygen Sensitivity Constant KO2	Oxygen Feed Constant KO3	Oxygen Time Interval TO1	Dissolved Oxygen Set Point DO_{SP}
d/m/y	hh:mm	Days	mg/min	milli-meter	psig	psig					min	mg/L
14-Dec-12	9:20	281	132.0	0.0	550.0	40.0	Feed Flow	0.03	0.5	1.0	10.0	5.0
17-Dec-12	12:25	284	130.0	0.0	450.0	40.0	Feed Flow	0.03	0.5	1.0	10.0	5.0
17-Dec-12	2:05	284	130.0	0.0	450.0	40.0	Feed Flow	0.03	0.5	1.0	10.0	5.0
19-Dec-12	9:20	286	130.0	0.0	400.0	40.0	Feed Flow	0.00	0.5	1.0	10.0	5.0
19-Dec-12	1:50	286	132.0	0.0	400.0	40.0	Feed Flow	0.00	0.5	1.0	10.0	5.0
20-Dec-12	8:45	287	13.0	0.0	350.0	40.0	Time step	0.01	0.5	1.0	10.0	5.0
2-Jan-13	9:30	300	133.0	0.0	1950.0	40.0	Time step	0.13	0.5	1.0	10.0	5.0
2-Jan-13	11:45	300	170.0	0.0	1950.0	40.0	Time step	0.17	0.5	1.0	10.0	5.0
3-Jan-13	8:30	301	138.0	0.0	1910.0	40.0	Time step	0.14	0.5	1.0	10.0	5.0
7-Jan-13	8:45	305	124.0	0.0	1800.0	40.0	Time step	0.13	0.5	1.0	10.0	5.0
9-Jan-13	12:45	307	108.0	0.0	1800.0	40.0	Time step	0.09	0.5	1.0	10.0	5.0
9-Jan-13	2:40	307	133.0	0.0	1750.0	40.0	Time step	0.13	0.5	1.0	10.0	5.0
11-Jan-13	8:45	309	110.0	0.0	1700.0	40.0	Time step	0.10	0.5	1.0	10.0	5.0
14-Jan-13	8:15	312	100.0	0.0	1510.0	40.0	Time step	0.09	0.5	1.0	10.0	5.0
14-Jan-13	10:00	312	110.0	0.0	1500.0	40.0	Time step	0.10	0.5	1.0	10.0	5.0
16-Jan-13	9:15	314	98.0	0.0	1500.0	40.0	Time step	0.08	0.5	1.0	10.0	5.0
17-Jan-13	3:15	315	133.0	0.0	1490.0	40.0	Time step	0.13	0.5	1.0	10.0	5.0
17-Jan-13	5:30	315	95.0	0.0	1490.0	40.0	Feed Flow	0.02	0.5	1.0	10.0	5.0
18-Jan-13	11:45	316	86.0	0.0	1450.0	40.0	Feed Flow	0.02	0.5	1.0	10.0	5.0
20-Jan-13	1:30	318	95.0	0.0	1410.0	40.0	Feed Flow	0.02	0.5	1.0	10.0	5.0
22-Jan-13	7:00	320	85.0	0.0	1340.0	40.0	Feed Flow	0.02	0.5	1.0	10.0	5.0
22-Jan-13	11:30	320	95.0	0.0	1340.0	40.0	Feed Flow	0.02	0.5	1.0	10.0	5.0
24-Jan-13	11:00	322	92.0	0.0	1310.0	40.0	Feed Flow	0.02	0.5	1.0	10.0	5.0
25-Jan-13	8:00	323	90.0	0.0	1310.0	40.0	Feed Flow	0.02	0.5	1.0	10.0	5.0

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR

Date	Time	Elapsed Time	Oxygen Mass Feed Flow FT-103	Oxygen Volumetric Feed Flow FI-103	Oxygen Tank Pressure T-120 PI	Oxygen Feed Pressure T-120 PI	Oxygen Feed Mode	Oxygen Proportionality Constant KO1	Oxygen Sensitivity Constant KO2	Oxygen Feed Constant KO3	Oxygen Time Interval TO1	Dissolved Oxygen Set Point DO_{SP}
d/m/y	hh:mm	Days	mg/min	milli-meter	psig	psig					min	mg/L
25-Jan-13	10:00	323	91.0	0.0	1310.0	40.0	Feed Flow	0.02	0.5	1.0	10.0	5.0
28-Jan-13	10:15	326	85.0	0.0	1250.0	40.0	Feed Flow	0.02	0.5	1.0	10.0	5.0
28-Jan-13	12:20	326	89.0	0.0	1250.0	40.0	Feed Flow	0.02	0.5	1.0	10.0	5.0
30-Jan-13	10:30	328	82.0	0.0	1150.0	40.0	Feed Flow	0.02	0.5	1.0	10.0	5.0
30-Jan-13	12:30	328	85.0	0.0	1150.0	40.0	Feed Flow	0.02	0.5	1.0	10.0	5.0
1-Feb-13	8:20	330	82.0	0.0	1100.0	40.0	Feed Flow	0.02	0.5	1.0	10.0	5.0
1-Feb-13	10:40	330	84.0	0.0	1100.0	40.0	Feed Flow	0.02	0.5	1.0	10.0	5.0
4-Feb-13	9:10	333	85.0	0.0	1090.0	40.0	Feed Flow	0.02	0.5	1.0	10.0	5.0
4-Feb-13	11:40	333	88.0	0.0	1090.0	40.0	Feed Flow	0.02	0.5	1.0	10.0	5.0
7-Feb-13	7:50	336	84.0	0.0	1010.0	40.0	Feed Flow	0.02	0.5	1.0	10.0	5.0
7-Feb-13	11:30	336	85.0	0.0	1010.0	40.0	Feed Flow	0.02	0.5	1.0	10.0	5.0
8-Feb-13	10:30	337	131.0	0.0	1000.0	40.0	Feed Flow	0.03	0.5	1.0	10.0	5.0
20-Feb-13	11:00	349	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
25-Feb-13	15:15	354	212.0	0.0	900.0	40.0	Feed Flow	0.05	0.5	1.0	10.0	5.0
27-Feb-13	11:35	356	130.0	0.0	750.0	40.0	Feed Flow	0.03	0.5	1.0	10.0	5.0
28-Feb-13	10:00	357	130.0	0.0	690.0	40.0	Feed Flow	0.03	0.5	1.0	10.0	5.0
28-Feb-13	12:30	357	123.0	0.0	650.0	40.0	Feed Flow	0.03	0.5	1.0	10.0	5.0
4-Mar-13	11:30	361	130.0	0.0	650.0	40.0	Feed Flow	0.03	0.5	1.0	10.0	5.0
6-Mar-13	7:40	363	132.0	0.0	510.0	40.0	Feed Flow	0.03	0.5	1.0	10.0	5.0
6-Mar-13	10:20	363	132.0	0.0	490.0	40.0	Feed Flow	0.03	0.5	1.0	10.0	5.0
8-Mar-13	8:30	365	132.0	0.0	490.0	40.0	Feed Flow	0.03	0.5	1.0	10.0	5.0
8-Mar-13	10:15	365	131.0	0.0	400.0	40.0	Feed Flow	0.03	0.5	1.0	10.0	5.0
11-Mar-13	10:15	368	130.0	0.0	400.0	40.0	Feed Flow	0.03	0.5	1.0	10.0	5.0
11-Mar-13	12:15	368	132.0	0.0	250.0	40.0	Time Step	0.13	0.5	1.0	10.0	5.0

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR

Date	Time	Elapsed Time	Oxygen Mass Feed Flow FT-103	Oxygen Volumetric Feed Flow FI-103	Oxygen Tank Pressure T-120 PI	Oxygen Feed Pressure T-120 PI	Oxygen Feed Mode	Oxygen Proportionality Constant KO1	Oxygen Sensitivity Constant KO2	Oxygen Feed Constant KO3	Oxygen Time Interval TO1	Dissolved Oxygen Set Point DO_{SP}
d/m/y	hh:mm	Days	mg/min	milli-meter	psig	psig					min	mg/L
13-Mar-13	1:15	370	130.0	0.0	200.0	40.0	Feed Flow	0.03	0.5	1.0	10.0	5.0
14-Mar-13	9:52	371	132.0	0.0	150.0	40.0	Feed Flow	0.03	0.5	1.0	10.0	5.0
15-Mar-13	7:30	372	132.0	0.0	100.0	40.0	Feed Flow	0.03	0.5	1.0	10.0	5.0
15-Mar-13	10:45	372	180.0	0.0	2400.0	40.0	Feed Flow	0.04	0.5	1.0	10.0	5.0
18-Mar-13	9:45	375	132.0	0.0	2050.0	40.0	Feed Flow	0.03	0.5	1.0	10.0	5.0
18-Mar-13	12:00	375	132.0	0.0	2050.0	40.0	Feed Flow	0.03	0.5	1.0	10.0	5.0
20-Mar-13	6:30	377	130.0	0.0	1950.0	40.0	Feed Flow	0.03	0.5	1.0	10.0	5.0

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR

Date	Time	Elapsed Time	Propane Mass Feed Flow FT-130	Propane Volumetric Feed Flow FI-130	Propane Tank Pressure T-130 PI	Propane Feed Pressure T-130 PI	Propane Feed Mode	Propane Proportionality Constant Kpf	Propane Proportionality Constant Kpo	Lower Explosive Limit AIT-110
d/m/y	hh:mm	Days	mg/min	milli-meter	psig	psig				%
8-Mar-12	9:02	0	0.0	0.0	N/A	N/A	N/A	N/A	N/A	0.0
12-Mar-12	8:27	4	0.0	0.0	N/A	N/A	N/A	N/A	N/A	0.0
12-Mar-12	11:00	4	0.0	0.0	N/A	N/A	N/A	N/A	N/A	0.0
14-Mar-12	8:28	6	0.0	0.0	N/A	N/A	N/A	N/A	N/A	0.0
16-Mar-12	9:30	8	0.0	0.0	N/A	N/A	N/A	N/A	N/A	0.0
19-Mar-12	10:00	11	0.0	0.0	N/A	N/A	N/A	N/A	N/A	0.0
21-Mar-12	8:05	13	0.0	0.0	N/A	N/A	N/A	N/A	N/A	0.0
23-Mar-12	12:00	15	0.0	0.0	N/A	N/A	N/A	N/A	N/A	0.0
26-Mar-12	15:30	18	0.0	0.0	N/A	N/A	N/A	N/A	N/A	0.0
27-Mar-12	8:00	19	0.0	0.0	N/A	N/A	N/A	N/A	N/A	0.0
27-Mar-12	11:33	19	0.0	0.0	N/A	N/A	N/A	N/A	N/A	0.0
30-Mar-12	12:45	22	0.0	0.0	N/A	N/A	N/A	N/A	N/A	0.0
2-Apr-12	16:00	25	0.0	0.0	N/A	N/A	N/A	N/A	N/A	0.0
4-Apr-12	8:00	27	0.0	0.0	N/A	N/A	N/A	N/A	N/A	0.0
5-Apr-12	9:30	28	0.0	0.0	N/A	N/A	N/A	N/A	N/A	0.0
10-Apr-12	9:15	33	0.0	0.0	N/A	N/A	N/A	N/A	N/A	0.0
16-Apr-12	13:30	39	0.0	0.0	N/A	N/A	N/A	N/A	N/A	2.0
18-Apr-12	12:30	41	0.0	0.0	N/A	N/A	N/A	N/A	N/A	2.0
19-Apr-12	10:30	42	0.0	0.0	N/A	N/A	N/A	N/A	N/A	1.0
24-Apr-12	9:08	47	0.0	0.0	N/A	N/A	N/A	N/A	N/A	2.0
26-Apr-12	12:00	49	0.0	0.0	N/A	N/A	N/A	N/A	N/A	2.0
30-Apr-12	10:15	53	0.0	0.0	N/A	N/A	N/A	N/A	N/A	2.0
30-Apr-12	14:00	53	0.0	0.0	N/A	N/A	N/A	N/A	N/A	2.0
30-Apr-12	15:00	53	0.0	0.0	N/A	N/A	N/A	N/A	N/A	2.0

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR										
Date	Time	Elapsed Time	Propane Mass Feed Flow FT-130	Propane Volumetric Feed Flow FI-130	Propane Tank Pressure T-130 PI	Propane Feed Pressure T-130 PI	Propane Feed Mode	Propane Proportionality Constant Kpf	Propane Proportionality Constant Kpo	Lower Explosive Limit AIT-110
d/m/y	hh:mm	Days	mg/min	milli-meter	psig	psig				%
1-May-12	15:30	54	0.0	0.0	N/A	N/A	N/A	N/A	N/A	1.0
3-May-12	11:15	56	0.0	0.0	N/A	N/A	N/A	N/A	N/A	1.0
3-May-12	12:00	56	0.0	0.0	N/A	N/A	N/A	N/A	N/A	1.0
3-May-12	13:30	56	0.0	0.0	N/A	N/A	N/A	N/A	N/A	1.0
7-May-12	11:15	60	0.0	0.0	N/A	N/A	N/A	N/A	N/A	1.0
10-May-12	16:45	63	0.0	0.0	N/A	N/A	N/A	N/A	N/A	1.0
14-May-12	8:15	67	0.0	0.0	N/A	N/A	N/A	N/A	N/A	2.0
14-May-12	12:15	67	0.0	0.0	N/A	N/A	N/A	N/A	N/A	2.0
15-May-12	15:00	68	0.0	0.0	N/A	N/A	N/A	N/A	N/A	2.0
21-May-12	14:15	74	17.0	0.0	150.0	25.0	feed	5.0	0.05	2.0
22-May-12	16:00	75	0.0	0.0	N/A	N/A	N/A	N/A	N/A	1.0
23-May-12	12:30	76	0.0	0.0	N/A	N/A	N/A	N/A	N/A	1.0
25-May-12	12:00	78	0.0	0.0	N/A	N/A	N/A	N/A	N/A	0.0
29-May-12	12:50	82	0.0	0.0	N/A	N/A	N/A	N/A	N/A	
30-May-12	13:05	83	0.0	0.0	N/A	N/A	N/A	N/A	N/A	0.0
30-May-12	14:50	83	0.0	0.0	N/A	N/A	N/A	N/A	N/A	1.0
30-May-12	16:08	83	10.0	0.0	150.0	28.0	Oxygen	1.0	0.10	1.0
31-May-12	8:00	84	9.0	0.0	150.0	29.0	Oxygen	1.0	0.09	1.0
31-May-12	9:15	84	15.0	0.0	150.0	25.0	Oxygen	1.0	0.15	0.0
31-May-12	10:30	84	16.0	0.0	150.0	25.0	Oxygen	1.0	0.15	
31-May-12	11:45	84	17.0	0.0	150.0	28.0	Oxygen	1.0	0.15	1.0
31-May-12	14:00	84	15.0	0.0	150.0	25.0	Oxygen	1.0	0.15	1.0
31-May-12	14:30	84	16.0	0.0	150.0	26.0	Oxygen	1.0	0.15	1.0
1-Jun-12	7:15	85	15.0	0.0	130.0	26.0	Oxygen	1.0	0.15	1.0

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR										
Date	Time	Elapsed Time	Propane Mass Feed Flow FT-130	Propane Volumetric Feed Flow FI-130	Propane Tank Pressure T-130 PI	Propane Feed Pressure T-130 PI	Propane Feed Mode	Propane Proportionality Constant Kpf	Propane Proportionality Constant Kpo	Lower Explosive Limit AIT-110
d/m/y	hh:mm	Days	mg/min	milli-meter	psig	psig				%
1-Jun-12	10:00	85	14.0	0.0	130.0	27.0	Oxygen	1.0	0.15	0.0
1-Jun-12	12:00	85	14.0	0.0	150.0	26.0	Oxygen	1.0	0.15	1.0
2-Jun-12	9:00	86	15.0	0.0	140.0	24.0	Oxygen	1.0	0.15	1.0
2-Jun-12	10:30	86	15.0	0.0	140.0	25.0	Oxygen	1.0	0.15	1.0
2-Jun-12	11:30	86	15.0	0.0	140.0	25.0	Oxygen	1.0	0.15	1.0
2-Jun-12	12:30	86	17.0	0.0	150.0	25.0	Oxygen	1.0	0.15	2.0
4-Jun-12	8:30	88	15.0	0.0	140.0	24.0	Oxygen	1.0	0.15	1.0
4-Jun-12	13:30	88	15.0	0.0	140.0	24.0	Oxygen	1.0	0.15	1.0
5-Jun-12	14:30	89	15.0	0.0	140.0	24.0	Oxygen	1.0	0.15	1.0
6-Jun-12	9:00	90	17.0	0.0	140.0	25.0	Oxygen	1.0	0.15	1.0
6-Jun-12	13:07	90	55.0	0.0	180.0	25.0	Feed Flow	76.0	0.15	9.0
6-Jun-12	15:40	90	51.0	0.0	170.0	25.0	Feed Flow	72.0	0.15	7.0
7-Jun-12	8:05	91	21.0	0.0	120.0	23.0	Feed Flow	42.0	0.15	3.0
7-Jun-12	10:40	91	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
7-Jun-12	12:00	91	43.0	0.0	170.0	23.0	Feed Flow	60.0	0.15	5.0
7-Jun-12	13:20	91	42.0	0.0	170.0	23.0	Feed Flow	60.0	0.15	5.0
8-Jun-12	8:00	92	42.0	0.0	150.0	23.0	Feed Flow	60.0	0.15	5.0
8-Jun-12	10:30	92	42.0	0.0	150.0	23.0	Feed Flow	60.0	0.15	5.0
8-Jun-12	12:15	92	42.0	0.0	180.0	25.0	Feed Flow	60.0	0.15	5.0
8-Jun-12	13:00	92	42.0	0.0	180.0	25.0	Feed Flow	60.0	0.15	5.0
8-Jun-12	14:00	92	42.0	0.0	180.0	25.0	Feed Flow	60.0	0.15	5.0
9-Jun-12	10:40	93	43.0	0.0	180.0	25.0	Feed Flow	60.0	0.15	6.0
9-Jun-12	12:00	93	72.0	0.0	180.0	25.0	Feed Flow	90.0	0.15	10.0

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR										
Date	Time	Elapsed Time	Propane Mass Feed Flow FT-130	Propane Volumetric Feed Flow FI-130	Propane Tank Pressure T-130 PI	Propane Feed Pressure T-130 PI	Propane Feed Mode	Propane Proportionality Constant Kpf	Propane Proportionality Constant Kpo	Lower Explosive Limit AIT-110
d/m/y	hh:mm	Days	mg/min	milli-meter	psig	psig				%
9-Jun-12	13:00	93	66.0	0.0	180.0	25.0	Feed Flow	92.0	0.15	9.0
9-Jun-12	14:00	93	68.0	0.0	180.0	25.0	Feed Flow	96.0	0.15	10.0
9-Jun-12	15:00	93	60.0	0.0	180.0	25.0	Feed Flow	90.0	0.15	10.0
11-Jun-12	7:50	95	59.0	0.0	120.0	23.0	Feed Flow	84.0	0.15	7.0
11-Jun-12	11:30	95	64.0	0.0	200.0	25.0	Feed Flow	92.0	0.15	9.0
11-Jun-12	13:00	95	67.0	0.0	180.0	25.0	Feed Flow	94.0	0.15	10.0
11-Jun-12	14:00	95	66.0	0.0	180.0	25.0	Feed Flow	94.0	0.15	9.0
13-Jun-12	8:00	97	66.0	0.0	100.0	24.0	Feed Flow	94.0	0.15	8.0
13-Jun-12	13:40	97	58.0	0.0	180.0	24.0	Feed Flow	94.0	0.15	10.0
13-Jun-12	15:00	97	66.0	0.0	170.0	23.0	Feed Flow	94.0	0.15	9.0
14-Jun-12	8:30	98	66.0	0.0	120.0	23.0	Feed Flow	94.0	0.15	9.0
14-Jun-12	9:00	98	N/A	N/A	N/A	N/A	Feed Flow	92.0	0.15	N/A
14-Jun-12	11:00	98	66.0	0.0	150.0	24.0	Feed Flow	92.0	0.15	10.0
15-Jun-12	8:00	99	64.0	0.0	120.0	23.0	Feed Flow	88.0	0.15	11.0
15-Jun-12	12:15	99	65.0	0.0	170.0	23.0	Feed Flow	88.0	0.15	10.0
16-Jun-12	22:00	100	63.0	0.0	150.0	23.0	Feed Flow	86.0	0.15	11.0
18-Jun-12	11:00	102	61.0	0.0	200.0	24.0	Feed Flow	84.0	0.15	10.0
20-Jun-12	10:00	104	61.0	0.0	160.0	25.0	Feed Flow	84.0	0.15	7.0
20-Jun-12	12:20	104	70.0	0.0	160.0	25.0	Feed Flow	88.0	0.15	8.0
22-Jun-12	9:00	106	58.0	0.0	130.0	25.0	Feed Flow	86.0	0.15	8.0
25-Jun-12	12:00	109	67.0	0.0	150.0	24.0	Feed Flow	86.0	0.15	10.0
27-Jun-12	9:00	111	67.0	0.0	130.0	22.0	Feed Flow	84.0	0.15	10.0
27-Jun-12	12:30	111	60.0	0.0	130.0	22.0	Feed Flow	84.0	0.15	9.0
28-Jun-12	10:25	112	62.0	0.0	190.0	20.0	Feed Flow	60.0	0.15	9.0

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR										
Date	Time	Elapsed Time	Propane Mass Feed Flow FT-130	Propane Volumetric Feed Flow FI-130	Propane Tank Pressure T-130 PI	Propane Feed Pressure T-130 PI	Propane Feed Mode	Propane Proportionality Constant Kpf	Propane Proportionality Constant Kpo	Lower Explosive Limit AIT-110
d/m/y	hh:mm	Days	mg/min	milli-meter	psig	psig				%
2-Jul-12	11:15	116	64.0	0.0	120.0	24.0	Feed Flow	58.0	0.15	10.0
3-Jul-12	8:45	117	58.0	0.0	100.0	22.0	Feed Flow	58.0	0.15	9.0
5-Jul-12	9:30	119	60.0	0.0	100.0	23.0	Feed Flow	58.0	0.15	9.0
7-Jul-12	17:45	121	60.0	0.0	100.0	23.0	Feed Flow	56.0	0.15	9.0
9-Jul-12	12:15	123	62.0	0.0	110.0	25.0	Feed Flow	56.0	0.15	10.0
11-Jul-12	10:40	125	55.0	0.0	100.0	23.0	Feed Flow	50.0	0.15	9.0
12-Jul-12	8:15	126	53.0	0.0	100.0	21.0	Feed Flow	50.0	0.15	8.0
12-Jul-12	11:45	126	51.0	0.0	110.0	25.0	Feed Flow	50.0	0.15	8.0
16-Jul-12	12:00	130	55.0	0.0	140.0	23.0	Feed Flow	50.0	0.15	8.0
19-Jul-12	17:00	133	60.0	6.0	130.0	23.0	Feed Flow	52.0	0.15	1.0
20-Jul-12	11:15	134	112.0	50.0	120.0	24.0	Feed Flow	70.0	0.15	0.0
23-Jul-12	11:45	137	40.0	50.0	120.0	25.0	Oxygen flow	80.0	0.15	0.0
24-Jul-12	20:45	138	32.0	0.0	110.0	26.0	Feed Flow	46.0	0.15	9.0
25-Jul-12	12:15	139	15.0	0.0	150.0	23.5	Oxygen flow	40.0	0.15	1.0
25-Jul-12	13:40	139	24.0	0.0	150.0	23.5	Oxygen flow	40.0	0.15	2.0
26-Jul-12	13:00	140	25.0	0.0	150.0	23.0	Oxygen flow	1.0	0.15	5.0
26-Jul-12	15:00	140	50.0	0.0	150.0	25.0	Feed Flow	50.0	0.15	8.0
27-Jul-12	11:15	141	44.0	0.0	140.0	24.0	Feed Flow	42.0	0.15	7.0
30-Jul-12	9:35	144	50.0	0.0	100.0	21.0	Feed Flow	48.0	0.15	7.0
1-Aug-12	11:40	146	53.0	0.0	140.0	20.0	Feed Flow	48.0	0.15	7.0
3-Aug-12	10:45	148	53.0	0.0	120.0	24.0	Feed Flow	48.0	0.15	7.0
6-Aug-12	11:20	151	53.0	0.0	120.0	22.0	Feed Flow	48.0	0.15	7.0
8-Aug-12	8:10	153	50.0	0.0	110.0	22.0	Feed Flow	48.0	0.15	7.0
8-Aug-12	14:20	153	28.0	0.0	120.0	22.0	Oxygen flow	1.0	0.15	3.0

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR										
Date	Time	Elapsed Time	Propane Mass Feed Flow FT-130	Propane Volumetric Feed Flow FI-130	Propane Tank Pressure T-130 PI	Propane Feed Pressure T-130 PI	Propane Feed Mode	Propane Proportionality Constant Kpf	Propane Proportionality Constant Kpo	Lower Explosive Limit AIT-110
d/m/y	hh:mm	Days	mg/min	milli-meter	psig	psig				%
9-Aug-12	13:30	154	49.0	0.0	120.0	23.0	Feed Flow	48.0	0.20	6.0
13-Aug-12	8:15	158	51.0	0.0	110.0	22.5	Feed Flow	50.0	0.15	6.0
13-Aug-12	12:10	158	55.0	0.0	120.0	23.0	Feed Flow	50.0	0.15	6.0
15-Aug-12	8:21	160	24.0	0.0	100.0	20.0	Time step	50.0	0.15	2.0
15-Aug-12	11:00	160	55.0	0.0	110.0	22.0	Feed Flow	50.0	0.15	6.0
16-Aug-12	12:00	161	60.0	0.0	110.0	22.0	Feed Flow	50.0	0.15	7.0
20-Aug-12	10:45	165	55.0	0.0	110.0	21.5	Feed Flow	50.0	0.15	7.0
20-Aug-12	13:00	165	50.0	0.0	120.0	22.0	Feed Flow	32.0	0.15	7.0
22-Aug-12	11:00	167	49.0	0.0	100.0	20.0	Feed Flow	32.0	0.15	7.0
23-Aug-12	11:30	168	21.0	0.0	100.0	25.0	Oxygen flow	1.0	0.150	2.0
23-Aug-12	17:00	168	45.0	0.0	100.0	25.0	Feed Flow	32.0	0.150	6.0
24-Aug-12	10:05	169	24.0	0.0	100.0	21.0	Oxygen flow	32.0	0.150	2.0
24-Aug-12	11:30	169	46.0	0.0	100.0	21.0	Feed flow	32.0	0.150	6.0
27-Aug-12	11:15	172	51.0	0.0	100.0	23.0	Feed flow	32.0	0.150	6.0
29-Aug-12	8:30	174	17.0	0.0	100.0	23.0	Oxygen flow	32.0	0.15	1.0
29-Aug-12	10:45	174	34.0	0.0	100.0	22.0	Oxygen flow	1.0	0.15	2.0
29-Aug-12	12:00	174	41.0	0.0	100.0	24.0	Feed Flow	32.0	0.15	6.0
30-Aug-12	7:50	175	46.0	0.0	100.0	26.0	Feed Flow	32.0	0.15	6.0
1-Sep-12	17:00	177	45.0	0.0	100.0	24.0	Feed Flow	32.0	0.15	7.0
2-Sep-12	11:30	178	20.0	0.0	100.0	20.0	Oxygen flow	32.0	0.15	2.0
2-Sep-12	15:00	178	48.0	0.0	100.0	25.0	Feed flow	32.0	0.15	7.0
5-Sep-12	12:45	181	50.0	0.0	110.0	22.0	Feed flow	32.0	0.15	8.0
6-Sep-12	8:05	182	50.0	0.0	100.0	22.0	Feed flow	32.0	0.15	7.0
10-Sep-12	11:00	186	51.0	0.0	90.0	20.0	Feed flow	32.0	0.15	7.0

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR										
Date	Time	Elapsed Time	Propane Mass Feed Flow FT-130	Propane Volumetric Feed Flow FI-130	Propane Tank Pressure T-130 PI	Propane Feed Pressure T-130 PI	Propane Feed Mode	Propane Proportionality Constant Kpf	Propane Proportionality Constant Kpo	Lower Explosive Limit AIT-110
d/m/y	hh:mm	Days	mg/min	milli-meter	psig	psig				%
12-Sep-12	10:30	188	46.0	0.0	100.0	25.0	Feed flow	32.0	0.15	7.0
12-Sep-12	11:00	188	46.0	0.0	100.0	24.0	Feed flow	32.0	0.15	7.0
14-Sep-12	7:30	190	20.0	0.0	100.0	26.0	Oxygen Flow	32.0	0.15	1.0
14-Sep-12	9:15	190	26.0	0.0	100.0	25.0	Oxygen Flow	32.0	0.15	5.0
15-Sep-12	9:30	191	20.0	0.0	90.0	21.0	Oxygen flow	32.0	0.15	2.0
15-Sep-12	11:10	191	41.0	0.0	95.0	25.0	Oxygen flow	32.0	0.15	5.0
17-Sep-12	15:30	193	25.0	0.0	100.0	23.0	Oxygen flow	32.0	0.15	3.0
17-Sep-12	17:30	193	28.0	0.0	100.0	25.0	Oxygen flow	32.0	0.15	5.0
19-Sep-12	9:45	195	46.0	0.0	100.0	22.0	Feed Flow	30.0	0.15	8.0
20-Sep-12	9:35	196	45.0	0.0	100.0	24.0	Feed Flow	30.0	0.15	7.0
24-Sep-12	11:00	200	45.0	0.0	100.0	23.0	Feed Flow	30.0	0.15	7.0
26-Sep-12	10:30	202	50.0	0.0	100.0	22.0	Feed Flow	30.0	0.15	8.0
28-Sep-12	9:20	204	50.0	0.0	95.0	27.0	Feed Flow	18.0	0.15	6.0
29-Sep-12	11:00	205	42.0	0.0	95.0	24.0	Feed Flow	18.0	0.15	6.0
1-Oct-12	9:45	207	42.0	0.0	95.0	25.0	Feed Flow	18.0	0.15	5.0
2-Oct-12	10:35	208	40.0	0.0	90.0	24.0	Feed Flow	18.0	0.15	6.0
3-Oct-12	9:00	209	40.0	0.0	85.0	21.0	Feed Flow	18.0	0.15	6.0
3-Oct-12	11:00	209	40.0	0.0	85.0	23.0	Feed Flow	18.0	0.15	6.0
4-Oct-12	9:30	210	40.0	0.0	85.0	26.0	Feed Flow	18.0	0.15	7.0
8-Oct-12	9:00	214	40.0	0.0	85.0	22.0	Feed Flow	18.0	0.15	6.0
9-Oct-12	15:00	215	35.0	0.0	80.0	24.0	Feed Flow	16.0	0.15	7.0
10-Oct-12	11:45	216	37.0	0.0	80.0	23.0	Feed Flow	16.0	0.15	6.0
11-Oct-12	12:00	217	35.0	0.0	75.0	24.0	Feed Flow	16.0	0.15	6.0
15-Oct-12	12:00	221	35.0	0.0	65.0	24.0	Feed Flow	16.0	0.15	5.0

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR										
Date	Time	Elapsed Time	Propane Mass Feed Flow FT-130	Propane Volumetric Feed Flow FI-130	Propane Tank Pressure T-130 PI	Propane Feed Pressure T-130 PI	Propane Feed Mode	Propane Proportionality Constant Kpf	Propane Proportionality Constant Kpo	Lower Explosive Limit AIT-110
d/m/y	hh:mm	Days	mg/min	milli-meter	psig	psig				%
15-Oct-12	13:00	221	35.0	0.0	65.0	23.5	Feed Flow	16.0	0.15	5.0
17-Oct-12	11:00	223	35.0	0.0	65.0	21.0	Feed Flow	16.0	0.15	6.0
17-Oct-12	12:00	223	35.0	0.0	65.0	23.0	Feed Flow	16.0	0.15	6.0
19-Oct-12	8:00	225	34.0	0.0	65.0	25.0	Feed Flow	16.0	0.15	5.0
19-Oct-12	11:50	225	35.0	0.0	65.0	24.0	Feed Flow	16.0	0.15	6.0
22-Oct-12	10:10	228	35.0	0.0	65.0	21.0	Feed Flow	16.0	0.15	5.0
22-Oct-12	12:30	228	34.0	0.0	65.0	23.0	Feed Flow	16.0	0.15	7.0
24-Oct-12	12:00	230	37.0	0.0	65.0	25.0	Feed Flow	16.0	0.15	6.0
25-Oct-12	8:15	231	35.0	0.0	70.0	23.0	Feed Flow	16.0	0.15	6.0
25-Oct-12	11:15	231	37.0	0.0	70.0	24.0	Feed Flow	16.0	0.15	5.0
27-Oct-12	14:45	233	37.0	0.0	65.0	26.0	Feed Flow	16.0	0.15	6.0
29-Oct-12	11:00	235	35.0	0.0	65.0	21.0	Feed Flow	16.0	0.15	6.0
29-Oct-12	12:30	235	34.0	0.0	65.0	23.0	Feed Flow	16.0	0.15	5.0
31-Oct-12	8:35	237	35.0	0.0	65.0	23.0	Feed Flow	16.0	0.15	5.0
31-Oct-12	12:45	237	37.0	0.0	65.0	25.0	Feed Flow	16.0	0.15	6.0
2-Nov-12	7:45	239	36.0	0.0	65.0	27.0	Feed Flow	16.0	0.15	6.0
2-Nov-12	11:40	239	42.0	0.0	65.0	25.0	Feed Flow	10.0	0.15	6.0
5-Nov-12	10:15	242	44.0	0.0	65.0	22.0	Feed Flow	10.0	0.15	6.0
5-Nov-12	12:15	242	42.0	0.0	65.0	24.0	Feed Flow	10.0	0.15	6.0
7-Nov-12	9:00	244	44.0	0.0	65.0	21.0	Feed Flow	10.0	0.15	7.0
7-Nov-12	2:00	244	43.0	0.0	65.0	23.0	Feed Flow	10.0	0.15	7.0
9-Nov-12	8:30	246	44.0	0.0	65.0	23.0	Feed Flow	10.0	0.15	8.0
9-Nov-12	11:20	246	41.0	0.0	65.0	24.0	Feed Flow	9.0	0.15	6.0
12-Nov-12	8:00	249	41.0	0.0	65.0	25.0	Feed Flow	9.0	0.15	7.0

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR										
Date	Time	Elapsed Time	Propane Mass Feed Flow FT-130	Propane Volumetric Feed Flow FI-130	Propane Tank Pressure T-130 PI	Propane Feed Pressure T-130 PI	Propane Feed Mode	Propane Proportionality Constant Kpf	Propane Proportionality Constant Kpo	Lower Explosive Limit AIT-110
d/m/y	hh:mm	Days	mg/min	milli-meter	psig	psig				%
12-Nov-12	13:30	249	40.0	0.0	50.0	26.0	Feed Flow	9.0	0.15	5.0
14-Nov-12	10:45	251	48.0	0.0	50.0	24.0	Feed Flow	11.0	0.15	7.0
14-Nov-12	12:30	251	47.0	0.0	50.0	25.0	Feed Flow	11.0	0.15	6.0
16-Nov-12	8:50	253	48.0	0.0	50.0	25.0	Feed Flow	11.0	0.15	7.0
16-Nov-12	10:50	253	50.0	0.0	50.0	26.0	Feed Flow	11.0	0.15	7.0
19-Nov-12	10:40	256	47.0	0.0	50.0	25.0	Feed Flow	11.0	0.15	5.0
19-Nov-12	12:25	256	50.0	0.0	45.0	24.0	Feed Flow	11.0	0.15	6.0
21-Nov-12	7:30	258	47.0	0.0	45.0	24.0	Feed Flow	11.0	0.15	6.0
21-Nov-12	10:30	258	48.0	0.0	45.0	25.0	Feed Flow	11.0	0.15	6.0
24-Nov-12	15:35	261	48.0	0.0	45.0	26.0	Feed Flow	11.0	0.15	6.0
26-Nov-12	9:30	263	48.0	0.0	45.0	25.0	Feed Flow	11.0	0.15	7.0
26-Nov-12	11:30	263	48.0	0.0	45.0	25.0	Feed Flow	11.0	0.15	6.0
28-Nov-12	10:15	265	47.0	0.0	50.0	23.0	Feed Flow	11.0	0.15	7.0
28-Nov-12	12:05	265	47.0	0.0	50.0	25.0	Feed Flow	11.0	0.15	7.0
30-Nov-12	8:50	267	47.0	0.0	50.0	23.0	Feed Flow	11.0	0.15	6.0
30-Nov-12	12:00	267	48.0	0.0	50.0	25.0	Feed Flow	11.0	0.15	6.0
3-Dec-12	7:50	270	48.0	0.0	50.0	23.5	Feed Flow	11.0	0.15	7.0
3-Dec-12	12:30	270	0.0	0.0	0.0	27.0	OFF	11.0	0.15	2.0
5-Dec-12	11:00	272	0.0	0.0	0.0	20.0	OFF	11.0	0.15	1.0
8-Dec-12	11:15	275	0.0	0.0	0.0	20.0	OFF	11.0	0.15	1.0
10-Dec-12	11:00	277	0.0	0.0	0.0	20.0	OFF	11.0	0.15	1.0
12-Dec-12	10:30	279	0.0	0.0	0.0	20.0	OFF	11.0	0.15	2.0
12-Dec-12	12:15	279	39.0	0.0	50.0	26.0	Feed Flow	9.0	0.15	7.0
14-Dec-12	7:00	281	39.0	0.0	50.0	27.0	Feed Flow	9.0	0.15	6.0

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR										
Date	Time	Elapsed Time	Propane Mass Feed Flow FT-130	Propane Volumetric Feed Flow FI-130	Propane Tank Pressure T-130 PI	Propane Feed Pressure T-130 PI	Propane Feed Mode	Propane Proportionality Constant Kpf	Propane Proportionality Constant Kpo	Lower Explosive Limit AIT-110
d/m/y	hh:mm	Days	mg/min	milli-meter	psig	psig				%
14-Dec-12	9:20	281	39.0	0.0	50.0	26.0	Feed Flow	9.0	0.15	6.0
17-Dec-12	12:25	284	39.0	0.0	50.0	26.0	Feed Flow	9.0	0.15	5.0
17-Dec-12	2:05	284	39.0	0.0	50.0	27.0	Feed Flow	9.0	0.15	5.0
19-Dec-12	9:20	286	39.0	0.0	50.0	26.0	Feed Flow	9.0	0.15	5.0
19-Dec-12	1:50	286	40.0	0.0	50.0	27.0	Feed Flow	9.0	0.15	6.0
20-Dec-12	8:45	287	7.0	0.0	50.0	28.0	Oxygen flow	1.0	0.15	2.0
2-Jan-13	9:30	300	13.0	0.0	40.0	25.0	Oxygen flow	0.9	0.089	5.0
2-Jan-13	11:45	300	15.0	0.0	40.0	25.0	Oxygen flow	0.9	0.089	5.0
3-Jan-13	8:30	301	12.0	0.0	40.0	27.0	Oxygen flow	0.9	0.089	5.0
7-Jan-13	8:45	305	12.0	0.0	40.0	26.0	Oxygen flow	0.9	0.089	5.0
9-Jan-13	12:45	307	7.0	0.0	40.0	26.0	Oxygen flow	0.9	0.089	5.0
9-Jan-13	2:40	307	12.0	0.0	40.0	27.0	Oxygen flow	0.9	0.089	5.0
11-Jan-13	8:45	309	10.0	0.0	40.0	26.5	Oxygen flow	0.9	0.089	5.0
14-Jan-13	8:15	312	9.0	0.0	40.0	25.0	Oxygen flow	0.9	0.089	3.0
14-Jan-13	10:00	312	10.0	0.0	40.0	25.0	Oxygen flow	0.9	0.089	3.0
16-Jan-13	9:15	314	9.0	0.0	40.0	25.0	Oxygen flow	0.9	0.089	3.0
17-Jan-13	3:15	315	12.0	0.0	40.0	27.0	Oxygen flow	0.9	0.089	5.0
17-Jan-13	5:30	315	18.0	0.0	40.0	25.0	Feed Flow	4.0	0.1	5.0
18-Jan-13	11:45	316	18.0	0.0	40.0	25.0	Feed Flow	4.0	0.1	5.0
20-Jan-13	1:30	318	23.0	0.0	40.0	25.0	Feed Flow	5.0	0.1	6.0
22-Jan-13	7:00	320	20.0	0.0	40.0	26.0	Feed Flow	5.0	0.1	5.0
22-Jan-13	11:30	320	25.0	0.0	40.0	26.0	Feed Flow	5.0	0.1	5.0
24-Jan-13	11:00	322	25.0	0.0	40.0	26.0	Feed Flow	6.0	0.1	6.0
25-Jan-13	8:00	323	24.0	0.0	40.0	25.0	Feed Flow	6.0	0.1	6.0

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR										
Date	Time	Elapsed Time	Propane Mass Feed Flow FT-130	Propane Volumetric Feed Flow FI-130	Propane Tank Pressure T-130 PI	Propane Feed Pressure T-130 PI	Propane Feed Mode	Propane Proportionality Constant Kpf	Propane Proportionality Constant Kpo	Lower Explosive Limit AIT-110
d/m/y	hh:mm	Days	mg/min	milli-meter	psig	psig				%
25-Jan-13	10:00	323	27.0	0.0	40.0	25.0	Feed Flow	6.0	0.1	5.0
28-Jan-13	10:15	326	25.0	0.0	40.0	24.0	Feed Flow	6.0	0.1	6.0
28-Jan-13	12:20	326	27.0	0.0	40.0	26.0	Feed Flow	6.0	0.1	5.0
30-Jan-13	10:30	328	25.0	0.0	40.0	26.0	Feed Flow	6.0	0.1	5.0
30-Jan-13	12:30	328	25.0	0.0	40.0	25.0	Feed Flow	6.0	0.1	5.0
1-Feb-13	8:20	330	24.0	0.0	40.0	25.5	Feed Flow	6.0	0.1	5.0
1-Feb-13	10:40	330	25.0	0.0	40.0	24.0	Feed Flow	6.0	0.1	6.0
4-Feb-13	9:10	333	25.0	0.0	40.0	25.0	Feed Flow	6.0	0.1	6.0
4-Feb-13	11:40	333	26.0	0.0	40.0	26.0	Feed Flow	6.0	0.1	6.0
7-Feb-13	7:50	336	25.0	0.0	40.0	26.0	Feed Flow	6.0	0.1	3.0
7-Feb-13	11:30	336	25.0	0.0	40.0	26.0	Feed Flow	6.0	0.1	5.0
8-Feb-13	10:30	337	22.0	0.0	40.0	26.0	Feed Flow	5.0	0.1	7.0
20-Feb-13	11:00	349	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
25-Feb-13	15:15	354	15.0	0.0	35.0	27.0	Feed Flow	3.0	0.15	7.0
27-Feb-13	11:35	356	10.0	0.0	35.0	25.0	Feed Flow	3.0	0.15	6.0
28-Feb-13	10:00	357	17.0	0.0	35.0	26.0	Feed Flow	4.0	0.15	6.0
28-Feb-13	12:30	357	17.0	0.0	35.0	25.0	Feed Flow	4.0	0.15	6.0
4-Mar-13	11:30	361	18.0	0.0	35.0	25.0	Feed Flow	4.0	0.15	6.0
6-Mar-13	7:40	363	18.0	0.0	35.0	26.0	Feed Flow	4.0	0.15	6.0
6-Mar-13	10:20	363	18.0	0.0	35.0	26.0	Feed Flow	4.0	0.15	6.0
8-Mar-13	8:30	365	18.0	0.0	35.0	24.0	Feed Flow	4.0	0.15	6.0
8-Mar-13	10:15	365	20.0	0.0	35.0	26.0	Feed Flow	4.0	0.15	6.0
11-Mar-13	10:15	368	20.0	0.0	35.0	25.0	Feed Flow	4.0	0.15	6.0
11-Mar-13	12:15	368	15.0	0.0	35.0	24.0	Oxygen flow	1.0	0.1	6.0

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR

Date	Time	Elapsed Time	Propane Mass Feed Flow FT-130	Propane Volumetric Feed Flow FI-130	Propane Tank Pressure T-130 PI	Propane Feed Pressure T-130 PI	Propane Feed Mode	Propane Proportionality Constant Kpf	Propane Proportionality Constant Kpo	Lower Explosive Limit AIT-110
d/m/y	hh:mm	Days	mg/min	milli-meter	psig	psig				%
13-Mar-13	1:15	370	18.0	0.0	35.0	25.0	Feed Flow	4.0	0.1	6.0
14-Mar-13	9:52	371	18.0	0.0	35.0	26.0	Feed Flow	4.0	0.1	6.0
15-Mar-13	7:30	372	18.0	0.0	35.0	26.0	Feed Flow	4.0	0.1	6.0
15-Mar-13	10:45	372	20.0	0.0	35.0	27.0	Feed Flow	4.0	0.1	6.0
18-Mar-13	9:45	375	18.0	0.0	35.0	25.0	Feed Flow	4.0	0.1	6.0
18-Mar-13	12:00	375	17.0	0.0	35.0	26.0	Feed Flow	4.0	0.1	6.0
20-Mar-13	6:30	377	16.0	0.0	35.0	27.0	Feed Flow	4.0	0.1	6.0

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR

Date	Time	Elapsed Time	Dissolved Oxygen Feed V-140 (Portable)	Ammonia-N Feed V-140 (Test Strips)	Phosphate-P Feed V-140(Test Strips)	pH Feed V-140 (Portable)	Temperature Feed V-140 (Portable)	Dissolved Oxygen Effluent V-166 (Portable)	Ammonia-N Effluent V-166 (Test Strips)	Phosphate-P Effluent V-166 (Test Strips)	pH Effluent V-166 (Portable)
d/m/y	hh:mm	Days	mg/L	mg/L	mg/L	pH unit	°C	mg/L	mg/L	mg/L	pH unit
8-Mar-12	9:02	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
12-Mar-12	8:27	4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
12-Mar-12	11:00	4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
14-Mar-12	8:28	6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
16-Mar-12	9:30	8	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
19-Mar-12	10:00	11	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
21-Mar-12	8:05	13	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
23-Mar-12	12:00	15	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
26-Mar-12	15:30	18	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
27-Mar-12	8:00	19	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
27-Mar-12	11:33	19	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
30-Mar-12	12:45	22	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2-Apr-12	16:00	25	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
4-Apr-12	8:00	27	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
5-Apr-12	9:30	28	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
10-Apr-12	9:15	33	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
16-Apr-12	13:30	39	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
18-Apr-12	12:30	41	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
19-Apr-12	10:30	42	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
24-Apr-12	9:08	47	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
26-Apr-12	12:00	49	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
30-Apr-12	10:15	53	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
30-Apr-12	14:00	53	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
30-Apr-12	15:00	53	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR											
Date	Time	Elapsed Time	Dissolved Oxygen Feed V-140 (Portable)	Ammonia-N Feed V-140 (Test Strips)	Phosphate-P Feed V-140(Test Strips)	pH Feed V-140 (Portable)	Temperature Feed V-140 (Portable)	Dissolved Oxygen Effluent V-166 (Portable)	Ammonia-N Effluent V-166 (Test Strips)	Phosphate-P Effluent V-166 (Test Strips)	pH Effluent V-166 (Portable)
d/m/y	hh:mm	Days	mg/L	mg/L	mg/L	pH unit	°C	mg/L	mg/L	mg/L	pH unit
1-May-12	15:30	54	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3-May-12	11:15	56	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3-May-12	12:00	56	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3-May-12	13:30	56	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
7-May-12	11:15	60	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
10-May-12	16:45	63	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
14-May-12	8:15	67	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
14-May-12	12:15	67	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
15-May-12	15:00	68	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
21-May-12	14:15	74	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
22-May-12	16:00	75	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
23-May-12	12:30	76	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
25-May-12	12:00	78	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
29-May-12	12:50	82	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
30-May-12	13:05	83	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
30-May-12	14:50	83	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
30-May-12	16:08	83	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
31-May-12	8:00	84	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
31-May-12	9:15	84	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
31-May-12	10:30	84	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
31-May-12	11:45	84	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
31-May-12	14:00	84	N/A	N/A	N/A	N/A	32.5	N/A	3.0	0.0	7.3
31-May-12	14:30	84	N/A	N/A	N/A	N/A	N/A	N/A	4.5	0.3	N/A
1-Jun-12	7:15	85	N/A	N/A	N/A	N/A	N/A	N/A	1.0	0.2	N/A

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR

Date	Time	Elapsed Time	Dissolved Oxygen Feed V-140 (Portable)	Ammonia-N Feed V-140 (Test Strips)	Phosphate-P Feed V-140(Test Strips)	pH Feed V-140 (Portable)	Temperature Feed V-140 (Portable)	Dissolved Oxygen Effluent V-166 (Portable)	Ammonia-N Effluent V-166 (Test Strips)	Phosphate-P Effluent V-166 (Test Strips)	pH Effluent V-166 (Portable)
d/m/y	hh:mm	Days	mg/L	mg/L	mg/L	pH unit	^{o}C	mg/L	mg/L	mg/L	pH unit
1-Jun-12	10:00	85	N/A	N/A	N/A	N/A	N/A	N/A	1.0	1.7	N/A
1-Jun-12	12:00	85	N/A	N/A	N/A	N/A	N/A	N/A	1.0	0.0	7.4
2-Jun-12	9:00	86	N/A	N/A	N/A	N/A	N/A	N/A	0.5	1.0	N/A
2-Jun-12	10:30	86	N/A	N/A	N/A	N/A	N/A	N/A	0.3	1.7	N/A
2-Jun-12	11:30	86	N/A	N/A	N/A	N/A	N/A	N/A	0.5	1.0	N/A
2-Jun-12	12:30	86	N/A	N/A	N/A	N/A	N/A	N/A	1.0	1.7	N/A
4-Jun-12	8:30	88	N/A	N/A	N/A	N/A	31.4	N/A	0.0	1.7	7.2
4-Jun-12	13:30	88	N/A	N/A	N/A	N/A	N/A	N/A	0.5	1.7	N/A
5-Jun-12	14:30	89	N/A	N/A	N/A	N/A	N/A	N/A	0.1	1.7	N/A
6-Jun-12	9:00	90	N/A	N/A	N/A	N/A	N/A	N/A	0.3	2.0	N/A
6-Jun-12	13:07	90	N/A	N/A	N/A	N/A	30.6	N/A	0.6	2.0	7.3
6-Jun-12	15:40	90	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
7-Jun-12	8:05	91	N/A	N/A	N/A	N/A	N/A	N/A	0.3	1.0	N/A
7-Jun-12	10:40	91	N/A	N/A	N/A	N/A	N/A	N/A	0.3	0.7	N/A
7-Jun-12	12:00	91	N/A	0.0	0.0	8.6	30.6	N/A	3.0	0.3	8.0
7-Jun-12	13:20	91	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
8-Jun-12	8:00	92	N/A	0.0	0.0	8.2	N/A	N/A	0.0	0.7	7.4
8-Jun-12	10:30	92	N/A	N/A	N/A	N/A	N/A	N/A	0.4	1.0	N/A
8-Jun-12	12:15	92	N/A	N/A	N/A	N/A	N/A	N/A	0.3	1.0	N/A
8-Jun-12	13:00	92	N/A	N/A	N/A	N/A	N/A	N/A	0.5	1.0	N/A
8-Jun-12	14:00	92	N/A	N/A	N/A	N/A	N/A	N/A	0.7	1.0	N/A
9-Jun-12	10:40	93	N/A	N/A	N/A	N/A	N/A	N/A	0.0	1.7	N/A
9-Jun-12	12:00	93	N/A	N/A	N/A	N/A	N/A	N/A	0.0	1.7	N/A

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR											
Date	Time	Elapsed Time	Dissolved Oxygen Feed V-140 (Portable)	Ammonia-N Feed V-140 (Test Strips)	Phosphate-P Feed V-140(Test Strips)	pH Feed V-140 (Portable)	Temperature Feed V-140 (Portable)	Dissolved Oxygen Effluent V-166 (Portable)	Ammonia-N Effluent V-166 (Test Strips)	Phosphate-P Effluent V-166 (Test Strips)	pH Effluent V-166 (Portable)
d/m/y	hh:mm	Days	mg/L	mg/L	mg/L	pH unit	^oC	mg/L	mg/L	mg/L	pH unit
9-Jun-12	13:00	93	N/A	N/A	N/A	N/A	N/A	N/A	0.3	1.3	N/A
9-Jun-12	14:00	93	N/A	N/A	N/A	N/A	N/A	N/A	0.8	1.3	N/A
9-Jun-12	15:00	93	N/A	N/A	N/A	N/A	N/A	N/A	0.8	1.3	N/A
11-Jun-12	7:50	95	N/A	0.0	0.1	8.6	23.9	N/A	0.5	1.3	7.5
11-Jun-12	11:30	95	N/A	N/A	N/A	N/A	N/A	N/A	0.3	0.7	N/A
11-Jun-12	13:00	95	N/A	N/A	N/A	N/A	N/A	N/A	1.0	0.2	N/A
11-Jun-12	14:00	95	N/A	N/A	N/A	N/A	N/A	N/A	0.8	0.7	N/A
13-Jun-12	8:00	97	N/A	0.0	0.0	9.5	24.1	N/A	0.3	0.3	8.6
13-Jun-12	13:40	97	N/A	N/A	N/A	N/A	N/A	N/A	0.5	1.3	N/A
13-Jun-12	15:00	97	N/A	N/A	N/A	N/A	N/A	N/A	0.6	1.3	7.5
14-Jun-12	8:30	98	N/A	N/A	N/A	N/A	N/A	N/A	0.5	0.7	N/A
14-Jun-12	9:00	98	N/A	N/A	N/A	N/A	N/A	N/A	0.3	0.3	N/A
14-Jun-12	11:00	98	N/A	N/A	N/A	N/A	N/A	N/A	1.0	1.0	N/A
15-Jun-12	8:00	99	N/A	0.0	0.0	8.9	24.6	N/A	0.3	1.0	7.8
15-Jun-12	12:15	99	N/A	0.0	0.0	N/A	N/A	N/A	0.5	0.7	N/A
16-Jun-12	22:00	100	N/A	N/A	N/A	N/A	N/A	N/A	0.5	0.7	N/A
18-Jun-12	11:00	102	4.8	0.0	0.0	9.2	24.6	6.0	0.5	0.7	7.6
20-Jun-12	10:00	104	4.5	0.0	0.0	9.0	24.6	5.5	0.0	0.7	7.3
20-Jun-12	12:20	104	N/A	N/A	N/A	N/A	N/A	5.7	0.5	0.7	7.4
22-Jun-12	9:00	106	4.6	0.0	0.1	9.0	25.2	6.2	1.0	1.0	7.3
25-Jun-12	12:00	109	4.7	0.0	0.0	8.8	26.7	6.5	0.5	0.7	7.5
27-Jun-12	9:00	111	4.5	0.0	0.0	8.9	25.6	6.2	0.5	0.7	7.6
27-Jun-12	12:30	111	N/A	N/A	N/A	N/A	N/A	N/A	0.5	0.7	N/A
28-Jun-12	10:25	112	4.6	0.0	0.0	8.9	25.7	6.6	1.0	1.3	7.7

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR

Date	Time	Elapsed Time	Dissolved Oxygen Feed V-140 (Portable)	Ammonia-N Feed V-140 (Test Strips)	Phosphate-P Feed V-140(Test Strips)	pH Feed V-140 (Portable)	Temperature Feed V-140 (Portable)	Dissolved Oxygen Effluent V-166 (Portable)	Ammonia-N Effluent V-166 (Test Strips)	Phosphate-P Effluent V-166 (Test Strips)	pH Effluent V-166 (Portable)
d/m/y	hh:mm	Days	mg/L	mg/L	mg/L	pH unit	^{o}C	mg/L	mg/L	mg/L	pH unit
2-Jul-12	11:15	116	4.4	0.1	0.1	8.5	25.6	5.2	2.0	1.3	7.8
3-Jul-12	8:45	117	4.8	0.0	0.1	8.5	25.6	5.5	0.8	1.3	7.8
5-Jul-12	9:30	119	4.8	0.0	0.0	8.5	25.3	6.2	0.5	1.0	7.7
7-Jul-12	17:45	121	N/A	N/A	N/A	N/A	N/A	N/A	0.6	0.7	N/A
9-Jul-12	12:15	123	4.7	0.0	0.0	8.5	25.3	6.5	1.0	1.0	7.8
11-Jul-12	10:40	125	5.0	0.0	0.0	8.5	25.2	6.6	0.5	0.7	7.8
12-Jul-12	8:15	126	4.8	0.0	0.0	8.6	25.1	6.5	0.3	1.0	7.5
12-Jul-12	11:45	126	N/A	N/A	N/A	N/A	N/A	N/A	1.0	1.0	N/A
16-Jul-12	12:00	130	4.6	0.0	0.0	8.7	25.2	6.2	0.6	1.3	7.4
19-Jul-12	17:00	133	4.6	0.0	0.0	8.5	25.7	10.0	0.5	1.0	8.4
20-Jul-12	11:15	134	4.7	0.0	0.0	8.6	25.2	5.3	1.0	1.3	8.6
23-Jul-12	11:45	137	4.6	0.0	0.0	8.5	27.8	6.0	0.5	0.7	8.3
24-Jul-12	20:45	138	4.6	0.0	0.0	8.6	25.1	4.5	0.5	0.5	8.2
25-Jul-12	12:15	139	N/A	N/A	N/A	N/A	N/A	5.2	0.3	0.3	7.5
25-Jul-12	13:40	139	N/A	N/A	N/A	N/A	N/A	N/A	0.8	1.0	N/A
26-Jul-12	13:00	140	N/A	N/A	N/A	N/A	N/A	5.0	0.5	0.7	7.5
26-Jul-12	15:00	140	4.8	0.0	0.0	8.4	28.1	6.8	0.5	1.3	7.7
27-Jul-12	11:15	141	4.7	0.0	0.0	8.5	25.9	5.4	1.0	1.0	7.8
30-Jul-12	9:35	144	5.2	0.0	0.0	8.4	25.2	6.2	1.0	1.0	7.8
1-Aug-12	11:40	146	5.0	0.0	0.0	8.5	25.4	6.0	0.5	1.0	7.8
3-Aug-12	10:45	148	4.8	0.0	0.0	8.4	25.2	5.8	1.0	0.7	7.7
6-Aug-12	11:20	151	4.6	0.0	0.0	8.5	25.4	6.3	0.5	0.7	7.5
8-Aug-12	8:10	153	4.5	0.0	0.0	8.5	25.1	6.4	0.3	0.3	7.3
8-Aug-12	14:20	153	N/A	N/A	N/A	N/A	N/A	N/A	0.5	1.0	N/A

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR												
Date	Time	Elapsed Time	Dissolved Oxygen Feed V-140 (Portable)	Ammonia-N Feed V-140 (Test Strips)	Phosphate-P Feed V-140(Test Strips)	pH Feed V-140 (Portable)	Temperature Feed V-140 (Portable)	Dissolved Oxygen Effluent V-166 (Portable)	Ammonia-N Effluent V-166 (Test Strips)	Phosphate-P Effluent V-166 (Test Strips)	pH Effluent V-166 (Portable)
d/m/y	hh:mm	Days	mg/L	mg/L	mg/L	pH unit	^oC	mg/L	mg/L	mg/L	pH unit
9-Aug-12	13:30	154	4.7	0.0	0.0	8.3	26.0	5.0	2.0	1.7	7.1
13-Aug-12	8:15	158	4.5	0.0	0.0	8.4	25.8	5.6	1.0	1.0	7.2
13-Aug-12	12:10	158	4.6	0.0	0.0	8.3	26.8	6.0	0.5	1.0	7.3
15-Aug-12	8:21	160	N/A	N/A	N/A	N/A	N/A	5.4	0.3	0.3	7.3
15-Aug-12	11:00	160	4.5	0.0	0.1	8.5	27.2	4.6	3.0	1.7	7.7
16-Aug-12	12:00	161	4.4	0.0	0.0	8.3	27.1	5.6	1.0	1.0	7.6
20-Aug-12	10:45	165	4.3	0.0	0.1	8.4	26.8	5.2	0.5	1.0	7.7
20-Aug-12	13:00	165	4.5	0.0	0.0	8.4	26.9	5.4	1.0	1.3	7.6
22-Aug-12	11:00	167	4.5	0.3	0.0	8.5	26.3	5.1	1.0	0.7	7.8
23-Aug-12	11:30	168	N/A	N/A	N/A	N/A	N/A	2.0	0.3	0.3	8.0
23-Aug-12	17:00	168	4.6	0.0	0.0	8.4	27.2	5.0	0.5	0.7	8.1
24-Aug-12	10:05	169	N/A	N/A	N/A	N/A	N/A	4.5	0.3	0.3	7.8
24-Aug-12	11:30	169	4.3	0.0	0.0	8.4	27.1	5.1	0.5	0.7	7.9
27-Aug-12	11:15	172	4.7	0.0	0.0	8.6	25.7	5.6	0.5	0.7	8.0
29-Aug-12	8:30	174	N/A	N/A	N/A	N/A	N/A	4.6	0.3	0.0	7.5
29-Aug-12	10:45	174	N/A	N/A	N/A	N/A	N/A	N/A	1.0	0.7	N/A
29-Aug-12	12:00	174	4.7	0.0	0.0	8.4	25.9	6.0	1.0	1.0	8.2
30-Aug-12	7:50	175	4.6	0.0	0.0	8.4	25.8	6.2	2.0	1.3	8.0
1-Sep-12	17:00	177	4.5	0.0	0.0	8.4	26.4	5.6	0.5	1.0	8.1
2-Sep-12	11:30	178	N/A	N/A	N/A	N/A	N/A	N/A	0.3	0.3	N/A
2-Sep-12	15:00	178	4.7	0.0	0.0	8.3	25.3	6.0	1.0	1.0	7.9
5-Sep-12	12:45	181	4.6	0.3	0.1	8.3	25.3	6.2	2.0	0.7	8.1
6-Sep-12	8:05	182	4.5	0.0	0.0	8.4	25.1	6.3	1.0	0.7	7.8
10-Sep-12	11:00	186	4.6	0.0	0.0	8.3	24.8	6.1	0.5	0.7	7.7

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR

Date	Time	Elapsed Time	Dissolved Oxygen Feed V-140 (Portable)	Ammonia-N Feed V-140 (Test Strips)	Phosphate-P Feed V-140(Test Strips)	pH Feed V-140 (Portable)	Temperature Feed V-140 (Portable)	Dissolved Oxygen Effluent V-166 (Portable)	Ammonia-N Effluent V-166 (Test Strips)	Phosphate-P Effluent V-166 (Test Strips)	pH Effluent V-166 (Portable)
d/m/y	hh:mm	Days	mg/L	mg/L	mg/L	pH unit	°C	mg/L	mg/L	mg/L	pH unit
12-Sep-12	10:30	188	4.7	0.3	0.0	7.8	23.8	5.4	2.0	0.1	8.1
12-Sep-12	11:00	188	N/A	N/A	N/A	N/A	N/A	N/A	2.0	0.7	N/A
14-Sep-12	7:30	190	N/A	N/A	N/A	N/A	N/A	4.3	0.3	0.0	7.7
14-Sep-12	9:15	190	N/A	N/A	N/A	N/A	N/A	4.0	3.0	1.3	7.8
15-Sep-12	9:30	191	N/A	N/A	N/A	N/A	N/A	4.0	0.3	0.3	7.9
15-Sep-12	11:10	191	N/A	N/A	N/A	N/A	N/A	4.1	3.0	1.7	7.8
17-Sep-12	15:30	193	N/A	N/A	N/A	N/A	N/A	4.0	0.0	0.3	7.3
17-Sep-12	17:30	193	N/A	N/A	N/A	N/A	N/A	3.8	2.0	1.3	7.5
19-Sep-12	9:45	195	4.4	0.0	0.0	7.1	24.4	5.0	0.5	1.7	6.7
20-Sep-12	9:35	196	4.3	0.0	0.0	7.2	24.3	5.5	1.0	1.3	7.0
24-Sep-12	11:00	200	4.7	0.0	0.1	6.5	24.4	5.5	0.5	0.7	6.6
26-Sep-12	10:30	202	4.5	0.0	0.0	6.7	24.3	5.2	1.0	1.0	6.7
28-Sep-12	9:20	204	4.3	0.0	0.0	7.3	24.2	5.1	0.5	0.7	7.2
29-Sep-12	11:00	205	4.4	0.0	0.0	7.7	23.6	4.8	0.5	0.7	7.5
1-Oct-12	9:45	207	4.2	0.1	0.0	7.3	23.6	4.6	0.5	0.3	7.1
2-Oct-12	10:35	208	4.1	0.1	0.1	7.3	23.4	4.8	0.5	0.7	7.5
3-Oct-12	9:00	209	4.1	0.0	0.0	7.6	23.2	4.6	0.3	0.1	7.4
3-Oct-12	11:00	209	4.1	0.0	0.0	7.5	23.1	4.6	0.5	0.7	7.4
4-Oct-12	9:30	210	4.3	0.3	0.0	7.3	23.1	4.6	1.0	1.0	7.5
8-Oct-12	9:00	214	4.2	0.0	0.0	7.2	23.1	4.8	0.5	0.7	7.5
9-Oct-12	15:00	215	4.1	0.0	0.0	7.4	24.1	3.4	0.5	0.7	7.7
10-Oct-12	11:45	216	4.2	0.3	0.1	7.1	23.4	5.0	1.0	1.0	6.9
11-Oct-12	12:00	217	4.1	0.0	0.0	7.0	23.6	4.5	0.5	0.7	7.2
15-Oct-12	12:00	221	4.3	0.0	0.0	6.9	24.2	4.9	0.0	0.3	7.0

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR												
Date	**Time**	**Elapsed Time**	**Dissolved Oxygen Feed V-140 (Portable)**	**Ammonia-N Feed V-140 (Test Strips)**	**Phosphate-P Feed V-140(Test Strips)**	**pH Feed V-140 (Portable)**	**Temperature Feed V-140 (Portable)**	**Dissolved Oxygen Effluent V-166 (Portable)**	**Ammonia-N Effluent V-166 (Test Strips)**	**Phosphate-P Effluent V-166 (Test Strips)**	**pH Effluent V-166 (Portable)**
d/m/y	**hh:mm**	**Days**	**mg/L**	**mg/L**	**mg/L**	**pH unit**	**°C**	**mg/L**	**mg/L**	**mg/L**	**pH unit**
15-Oct-12	13:00	221	4.2	0.0	0.0	6.9	23.5	4.8	0.5	0.7	7.1
17-Oct-12	11:00	223	4.4	0.0	0.0	7.0	23.0	4.9	0.0	0.7	7.0
17-Oct-12	12:00	223	4.3	0.0	0.0	7.0	23.3	4.8	0.8	0.7	7.1
19-Oct-12	8:00	225	4.4	0.0	0.1	6.6	21.8	4.9	1.0	1.0	6.9
19-Oct-12	11:50	225	4.3	0.0	0.0	6.7	22.4	4.8	0.8	0.7	7.0
22-Oct-12	10:10	228	4.1	0.0	0.0	7.0	22.9	4.7	0.5	0.7	7.3
22-Oct-12	12:30	228	4.2	0.0	0.0	7.0	23.2	4.9	1.0	1.0	7.3
24-Oct-12	12:00	230	4.1	0.0	0.0	6.8	23.4	4.7	0.5	0.7	7.2
25-Oct-12	8:15	231	4.5	0.0	0.1	7.7	21.2	4.5	0.5	0.7	7.5
25-Oct-12	11:15	231	4.4	0.0	0.0	7.7	22.1	4.6	0.5	1.0	7.6
27-Oct-12	14:45	233	4.3	0.0	0.0	6.7	22.9	4.8	1.0	0.7	6.9
29-Oct-12	11:00	235	4.2	0.0	0.0	6.6	22.8	4.9	0.5	0.3	6.8
29-Oct-12	12:30	235	4.3	0.0	0.0	6.6	22.8	4.9	1.0	0.7	6.9
31-Oct-12	8:35	237	4.4	0.0	0.0	7.4	22.3	4.2	0.5	0.1	7.3
31-Oct-12	12:45	237	4.3	0.0	0.0	7.6	22.9	4.0	1.0	0.3	7.8
2-Nov-12	7:45	239	4.4	0.0	0.1	7.5	21.2	3.9	0.8	0.7	7.8
2-Nov-12	11:40	239	4.2	0.3	0.2	7.3	23.3	4.0	0.5	1.3	7.2
5-Nov-12	10:15	242	4.0	0.0	0.0	7.0	22.9	3.8	0.5	0.7	7.1
5-Nov-12	12:15	242	4.1	0.0	0.0	7.0	23.4	3.7	0.5	0.7	7.2
7-Nov-12	9:00	244	4.0	0.0	0.0	7. 44	22.2	3.7	0.5	0.7	7.6
7-Nov-12	2:00	244	4.1	0.0	0.1	7.5	23.5	2.9	0.5	0.7	7.7
9-Nov-12	8:30	246	4.2	0.0	0.1	7.7	22.3	3.8	0.5	0.7	7.7
9-Nov-12	11:20	246	4.1	0.0	0.0	7.6	23.1	4.0	0.3	1.3	7.6
12-Nov-12	8:00	249	4.0	0.0	0.0	7.7	20.9	4.5	0.5	0.7	7.9

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR												
Date	Time	Elapsed Time	Dissolved Oxygen Feed V-140 (Portable)	Ammonia-N Feed V-140 (Test Strips)	Phosphate-P Feed V-140(Test Strips)	pH Feed V-140 (Portable)	Temperature Feed V-140 (Portable)	Dissolved Oxygen Effluent V-166 (Portable)	Ammonia-N Effluent V-166 (Test Strips)	Phosphate-P Effluent V-166 (Test Strips)	pH Effluent V-166 (Portable)
d/m/y	hh:mm	Days	mg/L	mg/L	mg/L	pH unit	^{o}C	mg/L	mg/L	mg/L	pH unit
12-Nov-12	13:30	249	4.1	0.0	0.0	7.8	22.3	4.1	0.5	1.0	7.9
14-Nov-12	10:45	251	4.0	0.0	0.1	7.1	21.6	4.1	0.3	0.7	7.2
14-Nov-12	12:30	251	4.1	0.0	0.0	7.2	21.8	4.2	0.5	0.7	7.3
16-Nov-12	8:50	253	4.0	0.0	0.0	7.2	21.9	3.5	0.5	1.0	7.3
16-Nov-12	10:50	253	4.1	0.0	0.2	7.7	22.4	3.6	1.0	1.3	7.4
19-Nov-12	10:40	256	4.1	0.0	0.0	7.3	22.3	3.5	0.5	0.3	7.4
19-Nov-12	12:25	256	4.0	0.0	0.1	7.5	23.1	3.6	0.5	0.7	7.6
21-Nov-12	7:30	258	4.1	0.3	0.1	7.3	21.9	3.6	0.3	1.0	7.5
21-Nov-12	10:30	258	4.0	0.0	0.0	7.3	22.3	3.7	0.5	1.0	7.5
24-Nov-12	15:35	261	4.0	0.0	0.0	7.3	22.3	3.8	0.5	0.7	7.6
26-Nov-12	9:30	263	4.2	0.0	0.0	7.8	22.0	4.0	0.5	0.7	7.9
26-Nov-12	11:30	263	4.1	0.0	0.0	7.7	22.3	3.9	0.5	0.7	8.0
28-Nov-12	10:15	265	4.1	0.0	0.0	7.7	22.0	3.6	0.3	0.3	7.5
28-Nov-12	12:05	265	4.0	0.0	0.0	7.7	22.3	3.5	0.5	0.7	7.6
30-Nov-12	8:50	267	4.6	0.0	0.1	8.2	21.7	3.6	0.3	1.0	8.1
30-Nov-12	12:00	267	4.4	0.0	0.0	8.3	22.3	3.6	0.5	1.0	8.2
3-Dec-12	7:50	270	4.2	0.0	0.0	7.7	21.7	3.8	0.3	0.7	7.6
3-Dec-12	12:30	270	4.3	0.0	0.0	7.8	22.4	5.2	0.3	0.7	7.7
5-Dec-12	11:00	272	4.2	0.0	0.1	7.7	22.3	4.0	0.0	0.3	7.6
8-Dec-12	11:15	275	4.0	0.0	0.0	7.6	22.5	3.8	0.0	0.0	7.7
10-Dec-12	11:00	277	4.6	0.0	0.0	8.0	20.6	4.1	0.0	0.0	8.2
12-Dec-12	10:30	279	4.5	0.0	0.0	8.1	21.7	4.0	0.0	0.0	8.2
12-Dec-12	12:15	279	4.4	0.0	0.0	8.2	21.9	4.1	0.0	0.3	8.3
14-Dec-12	7:00	281	4.3	0.0	0.0	8.1	22.5	4.0	0.3	0.7	8.4

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR											
Date	Time	Elapsed Time	Dissolved Oxygen Feed V-140 (Portable)	Ammonia-N Feed V-140 (Test Strips)	Phosphate-P Feed V-140(Test Strips)	pH Feed V-140 (Portable)	Temperature Feed V-140 (Portable)	Dissolved Oxygen Effluent V-166 (Portable)	Ammonia-N Effluent V-166 (Test Strips)	Phosphate-P Effluent V-166 (Test Strips)	pH Effluent V-166 (Portable)
d/m/y	hh:mm	Days	mg/L	mg/L	mg/L	pH unit	^{o}C	mg/L	mg/L	mg/L	pH unit
14-Dec-12	9:20	281	4.2	0.0	0.0	8.0	22.6	4.1	0.5	0.7	8.3
17-Dec-12	12:25	284	4.3	0.0	0.0	7.8	21.8	4.6	0.0	0.3	8.1
17-Dec-12	2:05	284	4.1	0.0	0.0	7.9	22.2	4.2	0.3	0.7	8.2
19-Dec-12	9:20	286	4.3	0.0	0.0	7.9	22.2	3.8	0.5	1.0	8.2
19-Dec-12	1:50	286	4.1	0.0	0.0	7.9	21.5	4.0	0.5	0.7	8.3
20-Dec-12	8:45	287	4.0	0.0	0.0	7.7	20.2	3.5	3.0	2.0	8.2
2-Jan-13	9:30	300	N/A	N/A	N/A	N/A	N/A	3.4	0.3	0.3	7.3
2-Jan-13	11:45	300	N/A	N/A	N/A	N/A	N/A	3.5	2.0	1.3	7.3
3-Jan-13	8:30	301	N/A	N/A	N/A	N/A	N/A	3.4	1.0	1.0	7.4
7-Jan-13	8:45	305	N/A	N/A	N/A	N/A	N/A	3.3	0.5	0.7	7.2
9-Jan-13	12:45	307	N/A	N/A	N/A	N/A	N/A	3.9	0.0	0.1	7.1
9-Jan-13	2:40	307	N/A	N/A	N/A	N/A	N/A	4.1	4.0	2.3	7.1
11-Jan-13	8:45	309	N/A	N/A	N/A	N/A	N/A	3.7	2.0	1.3	7.1
14-Jan-13	8:15	312	N/A	N/A	N/A	N/A	N/A	3.9	0.3	1.0	7.4
14-Jan-13	10:00	312	N/A	N/A	N/A	N/A	N/A	3.9	1.0	1.0	7.4
16-Jan-13	9:15	314	N/A	N/A	N/A	N/A	N/A	3.7	0.5	0.7	7.4
17-Jan-13	3:15	315	N/A	N/A	N/A	N/A	N/A	3.8	0.3	0.7	7.3
17-Jan-13	5:30	315	4.0	0.0	0.0	6.8	17.8	4.1	0.5	1.0	7.1
18-Jan-13	11:45	316	4.3	0.0	0.0	7.0	18.7	5.9	1.0	1.3	7.2
20-Jan-13	1:30	318	4.4	0.0	0.1	7.5	17.8	5.1	0.5	1.0	7.7
22-Jan-13	7:00	320	4.3	0.0	0.0	7.4	17.8	5.4	0.5	1.0	7.6
22-Jan-13	11:30	320	4.5	0.0	0.0	7.2	15.6	5.2	1.0	1.3	7.5
24-Jan-13	11:00	322	4.1	0.0	0.0	7.4	18.8	3.9	0.5	1.0	7.6
25-Jan-13	8:00	323	4.2	0.0	0.0	7.4	19.3	4.6	0.3	0.7	7.5

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR

Date	Time	Elapsed Time	Dissolved Oxygen Feed V-140 (Portable)	Ammonia-N Feed V-140 (Test Strips)	Phosphate-P Feed V-140(Test Strips)	pH Feed V-140 (Portable)	Temperature Feed V-140 (Portable)	Dissolved Oxygen Effluent V-166 (Portable)	Ammonia-N Effluent V-166 (Test Strips)	Phosphate-P Effluent V-166 (Test Strips)	pH Effluent V-166 (Portable)
d/m/y	hh:mm	Days	mg/L	mg/L	mg/L	pH unit	^{o}C	mg/L	mg/L	mg/L	pH unit
25-Jan-13	10:00	323	4.0	0.1	0.1	7.4	19.4	4.5	0.5	1.0	7.5
28-Jan-13	10:15	326	4.3	0.0	0.0	7.5	20.4	4.2	0.3	0.7	7.7
28-Jan-13	12:20	326	4.1	0.0	0.1	7.5	20.5	3.8	1.0	1.0	7.7
30-Jan-13	10:30	328	4.0	0.1	0.0	7.7	20.3	3.5	0.3	0.7	7.9
30-Jan-13	12:30	328	4.0	0.0	0.0	7.8	20.5	3.6	0.3	1.0	7.8
1-Feb-13	8:20	330	4.2	0.0	0.0	7.4	20.1	3.4	0.5	1.0	7.7
1-Feb-13	10:40	330	4.1	0.1	0.1	7.5	20.7	3.5	0.5	1.3	7.7
4-Feb-13	9:10	333	4.3	0.0	0.0	7.2	20.7	3.9	0.3	0.7	7.4
4-Feb-13	11:40	333	4.0	0.0	0.1	7.2	21.2	3.7	0.3	0.7	7.4
7-Feb-13	7:50	336	4.2	0.1	0.1	7.6	21.3	3.4	0.5	1.3	7.9
7-Feb-13	11:30	336	4.3	0.0	0.0	7.6	21.4	3.7	0.5	1.0	7.9
8-Feb-13	10:30	337	4.0	0.0	0.1	7.5	21.9	3.1	0.3	0.7	8.0
20-Feb-13	11:00	349	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
25-Feb-13	15:15	354	4.0	0.0	0.1	7.6	21.9	3.2	0.3	0.7	8.2
27-Feb-13	11:35	356	3.9	0.0	0.0	7.6	22.2	3.6	0.3	0.3	8.5
28-Feb-13	10:00	357	4.0	0.0	0.0	7.2	23.4	4.2	0.5	0.7	7.5
28-Feb-13	12:30	357	3.8	0.0	0.0	7.0	23.4	4.3	0.5	1.0	7.1
4-Mar-13	11:30	361	3.7	0.0	0.0	7.0	23.6	4.4	1.0	1.0	7.2
6-Mar-13	7:40	363	3.5	0.0	0.1	7.1	26.4	3.2	0.3	0.3	7.2
6-Mar-13	10:20	363	3.4	0.0	0.1	6.9	23.8	3.0	0.5	0.7	7.0
8-Mar-13	8:30	365	3.5	0.0	0.0	6.8	23.9	3.2	0.3	0.7	7.0
8-Mar-13	10:15	365	3.2	0.0	0.0	7.1	24.0	3.0	0.5	0.3	7.6
11-Mar-13	10:15	368	3.3	0.0	0.0	7.2	24.1	3.1	0.3	0.7	7.7
11-Mar-13	12:15	368	N/A	N/A	N/A	N/A	N/A	3.0	0.3	0.7	7.3

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR											
Date	Time	Elapsed Time	Dissolved Oxygen Feed V-140 (Portable)	Ammonia-N Feed V-140 (Test Strips)	Phosphate-P Feed V-140(Test Strips)	pH Feed V-140 (Portable)	Temperature Feed V-140 (Portable)	Dissolved Oxygen Effluent V-166 (Portable)	Ammonia-N Effluent V-166 (Test Strips)	Phosphate-P Effluent V-166 (Test Strips)	pH Effluent V-166 (Portable)
d/m/y	hh:mm	Days	mg/L	mg/L	mg/L	pH unit	^{o}C	mg/L	mg/L	mg/L	pH unit
13-Mar-13	1:15	370	3.2	0.0	0.0	7.0	24.2	3.3	0.3	1.0	7.4
14-Mar-13	9:52	371	3.3	0.3	0.1	6.9	23.6	3.0	0.5	1.0	7.5
15-Mar-13	7:30	372	3.0	0.0	0.0	7.0	23.8	2.9	0.3	0.7	7.5
15-Mar-13	10:45	372	3.3	0.1	0.1	7.0	24.2	2.6	0.5	1.0	7.5
18-Mar-13	9:45	375	3.1	0.5	0.0	7.2	24.1	3.8	0.0	0.3	6.9
18-Mar-13	12:00	375	3.2	0.3	0.0	7.2	24.3	3.9	0.5	0.7	7.2
20-Mar-13	6:30	377	3.0	0.5	0.1	7.0	23.8	3.6	0.5	1.0	7.5

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR			
Date	**Time**	**Elapsed Time**	**Notes on System**
d/m/y	**hh:mm**	**Days**	**None**
8-Mar-12	9:02	0	
12-Mar-12	8:27	4	
12-Mar-12	11:00	4	
14-Mar-12	8:28	6	
16-Mar-12	9:30	8	
19-Mar-12	10:00	11	
21-Mar-12	8:05	13	
23-Mar-12	12:00	15	
26-Mar-12	15:30	18	
27-Mar-12	8:00	19	
27-Mar-12	11:33	19	
30-Mar-12	12:45	22	
2-Apr-12	16:00	25	
4-Apr-12	8:00	27	
5-Apr-12	9:30	28	
10-Apr-12	9:15	33	
16-Apr-12	13:30	39	
18-Apr-12	12:30	41	
19-Apr-12	10:30	42	
24-Apr-12	9:08	47	
26-Apr-12	12:00	49	
30-Apr-12	10:15	53	
30-Apr-12	14:00	53	
30-Apr-12	15:00	53	

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR

Date	Time	Elapsed Time	Notes on System
d/m/y	hh:mm	Days	None
1-May-12	15:30	54	
3-May-12	11:15	56	
3-May-12	12:00	56	
3-May-12	13:30	56	
7-May-12	11:15	60	
10-May-12	16:45	63	
14-May-12	8:15	67	
14-May-12	12:15	67	
15-May-12	15:00	68	
21-May-12	14:15	74	
22-May-12	16:00	75	
23-May-12	12:30	76	
25-May-12	12:00	78	
29-May-12	12:50	82	
30-May-12	13:05	83	
30-May-12	14:50	83	Added 2 grams of DAP
30-May-12	16:08	83	
31-May-12	8:00	84	Added 4 grams of DAP
31-May-12	9:15	84	increased propane to 15 mg/min at 9:00am
31-May-12	10:30	84	Added 4 grams of DAP
31-May-12	11:45	84	Added 4 grams of DAP
31-May-12	14:00	84	Added 6 grams of DAP
31-May-12	14:30	84	
1-Jun-12	7:15	85	

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR			
Date	Time	Elapsed Time	Notes on System
d/m/y	hh:mm	Days	None
1-Jun-12	10:00	85	
1-Jun-12	12:00	85	Added 4 grams of DAP in solution
2-Jun-12	9:00	86	
2-Jun-12	10:30	86	Added 2 grams of UREA in solution at 11:00am
2-Jun-12	11:30	86	
2-Jun-12	12:30	86	
4-Jun-12	8:30	88	Added 2 grams Urea in solution to top of column.
4-Jun-12	13:30	88	
5-Jun-12	14:30	89	Added 2 grams of Urea in 1L of water to top of column
6-Jun-12	9:00	90	Added 2 grams of Urea in 1L of water to top of column
6-Jun-12	13:07	90	
6-Jun-12	15:40	90	
7-Jun-12	8:05	91	
7-Jun-12	10:40	91	
7-Jun-12	12:00	91	
7-Jun-12	13:20	91	
8-Jun-12	8:00	92	
8-Jun-12	10:30	92	
8-Jun-12	12:15	92	
8-Jun-12	13:00	92	
8-Jun-12	14:00	92	
9-Jun-12	10:40	93	
9-Jun-12	12:00	93	

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR			
Date	Time	Elapsed Time	Notes on System
d/m/y	hh:mm	Days	None
9-Jun-12	13:00	93	
9-Jun-12	14:00	93	
9-Jun-12	15:00	93	
11-Jun-12	7:50	95	
11-Jun-12	11:30	95	
11-Jun-12	13:00	95	
11-Jun-12	14:00	95	
13-Jun-12	8:00	97	
13-Jun-12	13:40	97	
13-Jun-12	15:00	97	
14-Jun-12	8:30	98	
14-Jun-12	9:00	98	
14-Jun-12	11:00	98	
15-Jun-12	8:00	99	
15-Jun-12	12:15	99	
16-Jun-12	22:00	100	
18-Jun-12	11:00	102	
20-Jun-12	10:00	104	
20-Jun-12	12:20	104	For Nitrodethylamine it has J next to it , J-Estimated value, greater than MDL but less than PQL
22-Jun-12	9:00	106	
25-Jun-12	12:00	109	For NDMA and Nitrodethylamine effluent it has J next to it , J-Estimated value
27-Jun-12	9:00	111	For NDMA effluent it has J next to it , J-Estimated value
27-Jun-12	12:30	111	
28-Jun-12	10:25	112	

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR			
Date	**Time**	**Elapsed Time**	**Notes on System**
d/m/y	**hh:mm**	**Days**	**None**
2-Jul-12	11:15	116	
3-Jul-12	8:45	117	
5-Jul-12	9:30	119	
7-Jul-12	17:45	121	
9-Jul-12	12:15	123	
11-Jul-12	10:40	125	For NDMA effluent it has J next to it , J-Estimated value, greater than MDL but less than PQL
12-Jul-12	8:15	126	
12-Jul-12	11:45	126	
16-Jul-12	12:00	130	For NDMA and Nitrodethylamine effluent it has J next to it , J-Estimated value,
19-Jul-12	17:00	133	
20-Jul-12	11:15	134	
23-Jul-12	11:45	137	
24-Jul-12	20:45	138	
25-Jul-12	12:15	139	I added 2 grams of Urea in solution & 4 grams of DAP in solution to top of column at 1pm
25-Jul-12	13:40	139	
26-Jul-12	13:00	140	
26-Jul-12	15:00	140	
27-Jul-12	11:15	141	
30-Jul-12	9:35	144	NDMA effluent <0.01 U - Undetected, indicates not found above the detection limit
1-Aug-12	11:40	146	For NDMA and Nitrodethylamine effluent it has J next to it , J-Estimated value
3-Aug-12	10:45	148	
6-Aug-12	11:20	151	NDMA and Nitrodimethylamine effluent <0.01 U - Undetected
8-Aug-12	8:10	153	NDMA effluent <0.01 U - Undetected and Nitrodimethylamine effluent has J-Estimated value
8-Aug-12	14:20	153	I added 2 grams of Urea in solution & 4 grams of DAP in solution to top of column at 1:00 pm

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR			
Date	**Time**	**Elapsed Time**	**Notes on System**
d/m/y	**hh:mm**	**Days**	**None**
9-Aug-12	13:30	154	
13-Aug-12	8:15	158	& Nitrodimethylamine effluent has J next to it, J-estimated value >MDL &<PQL
13-Aug-12	12:10	158	NDMA effluent <0.01 U - Undetected
15-Aug-12	8:21	160	
15-Aug-12	11:00	160	
16-Aug-12	12:00	161	NDMA effluent <0.01 U - Undetected, / Nitrodimethylamine effluent has J value
20-Aug-12	10:45	165	Effluent taken after SRT taken on 8/20/2012/
20-Aug-12	13:00	165	Effluent taken at V-149 by column/Nitrodimethylamine effluent has J next to it
22-Aug-12	11:00	167	NDMA and Nitrodimethylamine effluent <0.01 U - Undetected
23-Aug-12	11:30	168	
23-Aug-12	17:00	168	
24-Aug-12	10:05	169	
24-Aug-12	11:30	169	
27-Aug-12	11:15	172	NDMA and Nitrodimethylamine effluent <0.01 U - Undetected
29-Aug-12	8:30	174	I added 4 g of DAP and 2 g of Urea in 1 L solution for each nutrient to top of column at 10:00am
29-Aug-12	10:45	174	
29-Aug-12	12:00	174	
30-Aug-12	7:50	175	NDMA and Nitrodimethylamine effluent <0.01 U - Undetected
1-Sep-12	17:00	177	
2-Sep-12	11:30	178	
2-Sep-12	15:00	178	
5-Sep-12	12:45	181	NDMA and Nitrodimethylamine effluent <0.01 U - Undetected
6-Sep-12	8:05	182	NDMA and Nitrodimethylamine effluent <0.01 U - Undetected
10-Sep-12	11:00	186	NDMA and Nitrodimethylamine effluent <0.01 U - Undetected

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR			
Date	**Time**	**Elapsed Time**	**Notes on System**
d/m/y	**hh:mm**	**Days**	**None**
12-Sep-12	10:30	188	
12-Sep-12	11:00	188	NDMA and Nitrodimethylamine effluent <0.01 U - Undetected
14-Sep-12	7:30	190	At 8:00am, I added 4g of Urea and 4 g of DAP in 1 L solution for each nutrient to top of column
14-Sep-12	9:15	190	
15-Sep-12	9:30	191	At 10:00am, I added 6g of Urea and 6 g of DAP in 1 L solution for each nutrient to top of column
15-Sep-12	11:10	191	
17-Sep-12	15:30	193	At 4:00 pm, I added 4g of Urea and 4 g of DAP in 1 L solution for each nutrient to top of column
17-Sep-12	17:30	193	
19-Sep-12	9:45	195	
20-Sep-12	9:35	196	NDMA and Nitrodimethylamine effluent <0.01 U - Undetected
24-Sep-12	11:00	200	NDMA and Nitrodimethylamine effluent <0.01 U - Undetected
26-Sep-12	10:30	202	NDMA and Nitrodimethylamine effluent <0.01 U - Undetected, less than detection limit
28-Sep-12	9:20	204	
29-Sep-12	11:00	205	
1-Oct-12	9:45	207	
2-Oct-12	10:35	208	NDMA and Nitrodimethylamine effluent <0.01 U - Undetected, less than detection limit
3-Oct-12	9:00	209	
3-Oct-12	11:00	209	
4-Oct-12	9:30	210	NDMA and Nitrodimethylamine effluent <0.01 U - Undetected, < detection limit
8-Oct-12	9:00	214	
9-Oct-12	15:00	215	
10-Oct-12	11:45	216	NDMA and Nitrodimethylamine effluent <0.01 U - Undetected, < detection limit
11-Oct-12	12:00	217	NDMA and Nitrodimethylamine effluent <0.01 U - Undetected, < detection limit
15-Oct-12	12:00	221	NDMA and Nitrodimethylamine effluent <0.01 U - Undetected, < detection limit

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR			
Date	**Time**	**Elapsed Time**	**Notes on System**
d/m/y	**hh:mm**	**Days**	**None**
15-Oct-12	13:00	221	
17-Oct-12	11:00	223	
17-Oct-12	12:00	223	NDMA and Nitrodimethylamine effluent <0.01 U - Undetected,< detection limit
19-Oct-12	8:00	225	
19-Oct-12	11:50	225	
22-Oct-12	10:10	228	NDMA and Nitrodimethylamine effluent <0.01 U - Undetected, < detection limit
22-Oct-12	12:30	228	
24-Oct-12	12:00	230	NDMA and Nitrodimethylamine effluent <0.01 U - Undetected, < detection limit
25-Oct-12	8:15	231	
25-Oct-12	11:15	231	
27-Oct-12	14:45	233	
29-Oct-12	11:00	235	For NDMA effluent is J-Estimated value, MDL<J< PQL/ DMN effluent <0.01 U - Undetected
29-Oct-12	12:30	235	
31-Oct-12	8:35	237	For NDMA effluent is a J-Estimated value, MDL<J< PQL/ DMN effluent <0.01 U - Undetected
31-Oct-12	12:45	237	
2-Nov-12	7:45	239	
2-Nov-12	11:40	239	
5-Nov-12	10:15	242	For NDMA effluent is a J-Estimated value, MDL<J< PQL/ DMN effluent <0.01 U - Undetected
5-Nov-12	12:15	242	
7-Nov-12	9:00	244	For NDMA effluent is a J-Estimated value, MDL<J< PQL/ DMN effluent <0.01 U - Undetected
7-Nov-12	2:00	244	Double sample I took to see if higher NDMA from Ray adjusting UV well influent
9-Nov-12	8:30	246	
9-Nov-12	11:20	246	
12-Nov-12	8:00	249	NDMA and Nitrodimethylamine effluent <0.01 U - Undetected, < detection limit

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR			
Date	**Time**	**Elapsed Time**	**Notes on System**
d/m/y	**hh:mm**	**Days**	**None**
12-Nov-12	13:30	249	
14-Nov-12	10:45	251	NDMA and Nitrodimethylamine effluent <0.01 U - Undetected, indicates < detection limit
14-Nov-12	12:30	251	
16-Nov-12	8:50	253	
16-Nov-12	10:50	253	
19-Nov-12	10:40	256	NDMA and Nitrodimethylamine effluent <0.01 U - Undetected, indicates < detection limit
19-Nov-12	12:25	256	
21-Nov-12	7:30	258	
21-Nov-12	10:30	258	
24-Nov-12	15:35	261	
26-Nov-12	9:30	263	NDMA and Nitrodimethylamine effluent <0.01 U - Undetected, indicates < detection limit
26-Nov-12	11:30	263	
28-Nov-12	10:15	265	NDMA and Nitrodimethylamine effluent <0.01 U - Undetected, indicates < detection limit
28-Nov-12	12:05	265	
30-Nov-12	8:50	267	
30-Nov-12	12:00	267	
3-Dec-12	7:50	270	NDMA and Nitrodimethylamine effluent <0.01 U - Undetected, indicates < detection limit
3-Dec-12	12:30	270	
5-Dec-12	11:00	272	NDMA and Nitrodimethylamine effluent <0.01 U - Undetected, indicates < detection limit
8-Dec-12	11:15	275	
10-Dec-12	11:00	277	NDMA and Nitrodimethylamine effluent <0.01 U - Undetected, indicates < detection limit
12-Dec-12	10:30	279	
12-Dec-12	12:15	279	NDMA and Nitrodimethylamine effluent <0.01 U - Undetected, indicates < detection limit
14-Dec-12	7:00	281	

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR			
Date	**Time**	**Elapsed Time**	**Notes on System**
d/m/y	**hh:mm**	**Days**	**None**
14-Dec-12	9:20	281	
17-Dec-12	12:25	284	NDMA effluent and Nitrodimethylamine effluent <0.01 U - Undetected/ ND- non detected
17-Dec-12	2:05	284	
19-Dec-12	9:20	286	NDMA effluent and Nitrodimethylamine effluent <0.01 U - Undetected, indicates <detection limit
19-Dec-12	1:50	286	
20-Dec-12	8:45	287	Added 4 grams of Urea and 4 grams of DAP in 1 gallon of water to column at 8:40am
2-Jan-13	9:30	300	Added 4 grams of Urea and 4 grams of DAP in 1 gallon of water to column at 10:05 am
2-Jan-13	11:45	300	
3-Jan-13	8:30	301	
7-Jan-13	8:45	305	
9-Jan-13	12:45	307	Added 6 grams o Urea and 6 grams of DAP in 2 gallons of water to top of column at 1:20pm
9-Jan-13	2:40	307	
11-Jan-13	8:45	309	
14-Jan-13	8:15	312	Added 2 grams of Urea at 9:40am to top of column
14-Jan-13	10:00	312	
16-Jan-13	9:15	314	
17-Jan-13	3:15	315	
17-Jan-13	5:30	315	
18-Jan-13	11:45	316	
20-Jan-13	1:30	318	
22-Jan-13	7:00	320	NDMA effluent and Nitrodimethylamine effluent <0.01 U - Undetected, indicates < detection limit
22-Jan-13	11:30	320	
24-Jan-13	11:00	322	For NDMA effluent is a J-Estimated value, MDL >J< PQL/ DMN effluent <0.01 U - Undetected
25-Jan-13	8:00	323	

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR			
Date	**Time**	**Elapsed Time**	**Notes on System**
d/m/y	**hh:mm**	**Days**	**None**
25-Jan-13	10:00	323	
28-Jan-13	10:15	326	For NDMA effluent is a J-Estimated value, MDL >J< PQL/ DMN effluent <0.01 U - Undetected
28-Jan-13	12:20	326	
30-Jan-13	10:30	328	NDMA effluent and Nitrodimethylamine effluent <0.01 U - Undetected, indicates < detection limit
30-Jan-13	12:30	328	
1-Feb-13	8:20	330	
1-Feb-13	10:40	330	
4-Feb-13	9:10	333	For NDMA effluent is a, J-Estimated value, MDL >J< PQL/DMN effluent <0.01 U - Undetected
4-Feb-13	11:40	333	
7-Feb-13	7:50	336	NDMA effluent and Nitrodimethylamine effluent <0.01 U - Undetected, indicates < detection limit
7-Feb-13	11:30	336	
8-Feb-13	10:30	337	
20-Feb-13	11:00	349	NDMA effluent and Nitrodimethylamine effluent <0.01 U - Undetected, < detection limit
25-Feb-13	15:15	354	
27-Feb-13	11:35	356	
28-Feb-13	10:00	357	
28-Feb-13	12:30	357	For Nitrodimethylamine effluent is a , J-Estimated value, greater than MDL but less than PQL
4-Mar-13	11:30	361	
6-Mar-13	7:40	363	For Nitrodimethylamine effluent is a , J-Estimated value, greater than MDL but less than PQL
6-Mar-13	10:20	363	
8-Mar-13	8:30	365	Nitrodimethylamine effluent <0.01 U - Undetected, indicates not found above the detection limit
8-Mar-13	10:15	365	
11-Mar-13	10:15	368	
11-Mar-13	12:15	368	

Appendix B: FBR Monitoring Data

WHITE SANDS TESTING FACILITY DAILY MONITORING LOGSHEET FOR NDMA FBR			
Date	**Time**	**Elapsed Time**	**Notes on System**
d/m/y	**hh:mm**	**Days**	**None**
13-Mar-13	1:15	370	NDMA effluent and DMN effluent <0.01 U - Undetected, < detection limit/ ND-non detected
14-Mar-13	9:52	371	NDMA effluent and DMN effluent <0.01 U - Undetected, indicates < detection limit
15-Mar-13	7:30	372	
15-Mar-13	10:45	372	
18-Mar-13	9:45	375	Nitrodimethylamine effluent <0.01 U - Undetected, indicates not found above the detection limit
18-Mar-13	12:00	375	
20-Mar-13	6:30	377	Nitrodimethylamine effluent <0.01 U - Undetected, indicates not found above the detection limit

Concentration of propane (μg/L) in the influent groundwater and effluent from the FBR.

	Days		Influent		(V-135) Influent		(after SRT) Effluent		(V-149) Effluent
4/5/2012	27	U	6.0		NS	U	6.0		NS
4/10/2012	33	U	6.0		NS	U	6.0		NS
6/6/2012	90	U	6.0		NS		42.6		NS
6/11/2012	95	U	6.0		NS		33.1		25.9
6/13/2012	97	U	6.0		NS		48.8		26.2
6/18/2012	102	U	6.0		NS		34.2		22.6
6/20/2012	104	U	6.0		NS		32.5		26.3
6/25/2012	109	U	6.0		NS		45.6		27.9
6/27/2012	111		861		NS		34.9		NS
7/3/2012	117		NS		810		31.8		NS
7/5/2012	119		NS		931		36.5		NS
7/9/2012	121		NS		1030		41.3		NS
7/11/2012	125		NS		689		36.6		NS
7/16/2012	130		NS		1030		37.1		NS
7/31/2012	145		NS		947		30.8		NS
8/2/2012	145		NS		876		31.4		NS
8/6/2012	151		NS		834		23.1		NS
8/8/2012	153		NS		1040		26.6		NS
8/13/2012	158		NS		1060		20.1		NS
8/16/2012	161		NS	U	6.0		28.4		NS
8/20/2012	165		NS		1140		32.2		NS
8/22/2012	167		NS		1000		21.7		NS
8/27/2012	172		NS		847		29.9		NS
8/30/2012	175		NS		798		28.2		NS
9/5/2012	181		NS		899		26.6		NS
9/6/2012	182		NS		882		29.6		NS
9/10/2012	186		NS		681		30.7		NS
9/12/2012	188		NS		679		27.3		NS
9/20/2012	196		NS		888		29.3		NS
9/24/2012	200		NS		608		30.4		NS
9/26/2012	202		NS		769		32.0		NS
10/2/2012	208		NS		396		20.3		NS
10/4/2012	210		NS		769		27.5		NS
10/10/2012	216		NS	U	6.0		21.7		NS
10/11/2012	217		NS	U	6.0		17.4		NS
10/15/2012	221		NS	U	6.0		20.2		NS
10/17/2012	223		NS	U	6.0		23.4		NS
10/22/2012	228		NS	U	6.0		20.7		NS
10/24/2012	230		NS	U	6.0		19.1		NS
10/29/2012	235		NS		232		20.9		NS
11/5/2012	242		NS		870		32.6		NS
11/7/2012	244		NS		730		30.0		NS
11/12/2012	249		NS		780		25.6		NS
11/14/2012	251		NS		998		34.1		NS
11/19/2012	256		NS		1070		64.3		NS
11/26/2012	263		NS		892		25.7		NS
11/28/2012	265		NS		730		29.4		NS
12/3/2012	270		NS		594		26.2		NS
12/5/2012	272		NS	U	6.0	U	6.0		NS
12/10/2012	277		NS	U	6.0	U	6.0		NS
12/12/2012	279		NS	U	6.0	U	6.0		NS
12/17/2012	284		NS		533		23.6		NS
12/19/2012	286		NS		790		20.5		NS
1/22/2013	320		NS		336		6.15		NS
1/24/2013	322		NS		175		11.4		NS
1/28/2013	326		NS		145	J	3.66		NS
1/30/2013	328		NS		29.7	J	3.43		NS
2/4/2013	333		NS		142	J	4.10		NS
2/7/2013	336		NS		251	J	4.19		NS
2/11/2013	257		NS		174	J	2.64		NS
2/28/2013	357		NS		159	J	3.13		NS
3/4/2013	361		NS		119	J	2.61		NS
3/6/2013	363		NS		158	J	2.05		NS
3/13/2013	370		NS		277		9.24		NS
3/14/2013	371		NS		316		6.88		NS
3/18/2013	375		NS		79	U	6.0		NS
3/20/2013	377		NS		89	J	1.76		NS

NS - Not Sampled

U - The compound was not detected at the indicated PQL

J - The compound was detected at a level below the method PQL. The value reported is an estimated value.

Concentration of orthophosphate (mg/L) in the influent groundwater and effluent from the FBR.

					(V-135)		(after SRT)		(V-149)
	Days		Influent		Influent		Effluent		Effluent
4/5/2012	27	U	0.2		NS	U	0.2		NS
4/10/2012	33	U	0.2		NS	U	0.2		NS
6/6/2012	90	U	0.2		NS		7.08		NS
6/11/2012	95	U	0.2		NS		0.84		NS
6/13/2012	97	U	0.2		NS		1.19		NS
6/18/2012	102	U	0.2		NS		1.25		NS
6/20/2012	104	U	0.2		NS		1.28		NS
6/25/2012	109	U	0.2		NS		1.25		NS
6/27/2012	111	U	0.2		NS		1.25		NS
7/3/2012	117	U	0.2		NS		1.25		NS
7/5/2012	119	U	0.2		NS		1.25		NS
7/9/2012	121	U	0.2		NS		0.83		NS
7/11/2012	125	U	0.2		NS		1.03		NS
7/16/2012	130	U	0.2		NS		1.25		NS
7/30/2012	144		0.57		NS		1.05		NS
8/2/2012	145		0.36		NS		1.45		NS
8/6/2012	151		0.63		NS		1.13		NS
8/8/2012	153		0.52		NS		0.97		NS
8/13/2012	158	J	0.18		NS		1.03		NS
8/16/2012	161		0.48		NS		1.04		NS
8/20/2012	165		0.31		NS		1.04		NS
8/22/2012	167		0.24		NS		1.34		NS
8/27/2012	172		0.31		NS		0.92		NS
8/30/2012	175		0.48		NS		0.82		NS
9/5/2012	181		0.27		NS		0.69		NS
9/6/2012	182		0.24		NS		0.45		NS
9/10/2012	186		0.40		NS		0.89		NS
9/12/2012	188		0.21		NS	U	0.2		NS
9/20/2012	196	J	0.13		NS		0.58		NS
9/24/2012	200	U	0.2		NS		0.28		NS
9/26/2012	202	U	0.2		NS	J	0.15		NS
10/2/2012	208	U	0.2		NS	U	0.2		NS
10/4/2012	210	U	0.2		NS	U	0.2		NS
10/10/2012	216	U	0.2		NS	U	0.2		NS
10/11/2012	217	U	0.2		NS	U	0.2		NS
10/15/2012	221	U	0.2		NS	U	0.2		NS
10/17/2012	223	U	0.2		NS	U	0.2		NS
10/22/2012	228	U	0.2		NS	U	0.2		NS
10/24/2012	230	U	0.2		NS	U	0.2		NS
10/29/2012	235	U	0.2		NS	U	0.2		NS
11/5/2012	242		0.46		NS		0.41		NS
11/7/2012	244		0.34		NS		0.67		NS
11/12/2012	249		0.29		NS		0.20		NS
11/14/2012	251	U	0.5		NS	J	0.16		NS
11/19/2012	256	U	0.2		NS	U	0.2		NS
11/26/2012	263	U	0.2		NS	U	0.2		NS
11/28/2012	265	U	0.2		NS	U	0.2		NS
12/3/2012	270	U	0.2		NS	U	0.2		NS
12/5/2012	272	U	0.2		NS	U	0.2		NS
12/10/2012	277	U	0.2		NS	U	0.2		NS
12/12/2012	279	U	0.2		NS	U	0.2		NS
12/17/2012	284	U	0.2		NS	U	0.2		NS
12/19/2012	286	U	0.2		NS	U	0.2		NS
1/22/2013	320	U	0.2		NS	U	0.2		NS
1/24/2013	322	U	0.2		NS	U	0.2		NS
1/28/2013	326	U	0.2		NS	U	0.2		NS
1/30/2013	328	U	0.2		NS	U	0.2		NS
2/4/2013	333	U	0.2		NS	U	0.2		NS
2/7/2013	336	U	0.2		NS	U	0.2		NS
2/11/2013 (1)	257	U	0.2		NS	U	0.2		NS
2/28/2013	357	U	0.2		NS	U	0.2		NS
3/4/2013	361	U	0.2		NS	U	0.2		NS
3/6/2013	363	U	0.2		NS	U	0.2		NS
3/13/2013	370	U	0.2		NS	U	0.2		NS
3/14/2013	371	U	0.2		NS	U	0.2		NS
3/18/2013	375	U	0.2		NS	U	0.2		NS
3/20/2013	377	U	0.2		NS	U	0.2		NS

NS - Not Sampled

U - The compound was not detected at the indicated PQL

J - The compound was detected at a level below the method PQL. The value reported is an estimated value.

(1) Infuent from before FCV-104

Concentration of ammonia-N (mg/L) in the influent groundwater and effluent from the FBR.

	Days		Influent		(V-135) Influent		(after SRT) Effluent		(V-149) Effluent
4/5/2012	27	J	0.22		NS	J	0.11		NS
4/10/2012	33	U	0.5		NS	U	0.5		NS
6/6/2012	90	J	0.14		NS	U	0.5		NS
6/11/2012	95	U	0.5		NS	U	0.5		NS
6/13/2012	97	U	0.5		NS	U	0.5		NS
6/18/2012	102	U	0.5		NS	U	0.5		NS
6/20/2012	104	U	0.5		NS	J	0.25		NS
6/25/2012	109	U	0.5		NS	U	0.5		NS
6/27/2012	111	J	0.14		NS	J	0.19		NS
7/3/2012	117	J	0.11		NS	U	0.5		NS
7/5/2012	119	U	0.5		NS	U	0.5		NS
7/9/2012	121	U	0.5		NS	U	0.5		NS
7/11/2012	125	U	0.5		NS	U	0.5		NS
7/16/2012	130	U	0.5		NS	U	0.5		NS
7/31/2012	145	U	0.5		NS	J	0.14		NS
8/2/2012	145	J	0.19		NS	J	0.11		NS
8/6/2012	151	U	0.5		NS	U	0.5		NS
8/8/2012	153	U	0.5		NS	U	0.5		NS
8/13/2012	158	J	0.11		NS	J	0.11		NS
8/16/2012	161	J	0.14		NS	J	0.17		NS
8/20/2012	165	U	0.5		NS	U	0.5		NS
8/22/2012	167	U	0.5		NS	J	0.11		NS
8/27/2012	172	J	0.14		NS	U	0.5		NS
8/30/2012	175	U	0.5		NS	U	0.5		NS
9/5/2012	181	J	0.11		NS	J	0.17		NS
9/6/2012	182	J	0.11		NS	U	0.5		NS
9/10/2012	186	U	0.5		NS	J	0.39		NS
9/20/2012	196	U	0.5		NS	U	0.5		NS
9/24/2012	200	U	0.5		NS	U	0.5		NS
10/2/2012	208	U	0.5		NS	U	0.5		NS
10/10/2012	216	U	0.5		NS	U	0.5		NS
10/11/2012	217	U	0.5		NS	U	0.5		NS
10/17/2012	223	U	0.5		NS	J	0.11		NS
10/22/2012	228	J	0.28		NS	J	0.28		NS
10/29/2012	235	J	0.14		NS	J	0.14		NS
11/5/2012	242	U	0.5		NS	J	0.11		NS
11/12/2012	249	U	0.2		NS	U	0.5		NS
11/19/2012	256	U	0.5		NS	U	0.5		NS
11/26/2012	263	J	0.17		NS	U	0.5		NS
12/3/2012	270	U	0.5		NS	U	0.5		NS
12/10/2012	277	J	0.22		NS	J	0.17		NS
12/17/2012	284	J	0.11		NS	J	0.11		NS
1/22/2013	320	J	0.11		NS	J	0.30		NS
1/28/2013	326	J	0.30		NS	J	0.25		NS
2/4/2013	336	J	0.19		NS	J	0.11		NS
2/11/2013 (1)	257	U	0.5		NS	U	0.5		NS
2/28/2013	357	J	0.17		NS	J	0.15		NS
3/4/2013	361	J	0.12		NS	U	0.50		NS
3/13/2013	370	J	0.25		NS	J	0.28		NS
3/18/2013	375	J	0.25		NS	J	0.22		NS
3/20/2013	377	J	0.19		NS	J	0.19		NS

NS - Not Sampled

U - The compound was not detected at the indicated PQL

J - The compound was detected at a level below the method PQL. The value reported is an estimated value.

(1) Infuent from before FCV-104

Concentration of nitrate-N (mg/L) in the influent groundwater and effluent from the FBR.

			(V-135)	(after SRT)	(V-149)
	Days	Influent	Influent	Effluent	Effluent
4/5/2012	27	1.78	NS	1.58	NS
4/10/2012	33	1.57	NS	1.59	NS
6/6/2012	90	1.43	NS	1.03	NS
6/11/2012	95	1.69	NS	1.22	NS
6/13/2012	97	1.70	NS	1.55	NS
6/18/2012	102	1.70	NS	1.89	NS
6/20/2012	104	1.71	NS	1.87	NS
6/25/2012	109	1.81	NS	2.38	NS
6/27/2012	111	1.70	NS	2.32	NS
7/3/2012	117	1.80	NS	2.38	NS
7/5/2012	119	1.81	NS	2.24	NS
7/9/2012	121	1.67	NS	2.18	NS
7/11/2012	125	1.82	NS	2.40	NS
7/16/2012	130	1.86	NS	2.41	NS
7/30/2012	144	1.54	NS	3.07	NS
8/2/2012	145	1.98	NS	2.62	NS
8/6/2012	151	1.75	NS	3.37	NS
8/8/2012	153	3.78	NS	4.54	NS
8/13/2012	158	1.88	NS	2.04	NS
8/16/2012	161	1.92	NS	2.94	NS
8/20/2012	165	2.04	NS	3.00	NS
8/22/2012	167	1.81	NS	2.70	NS
8/27/2012	172	2.09	NS	2.85	NS
8/30/2012	175	1.87	NS	2.69	NS
9/5/2012	181	1.80	NS	2.61	NS
9/6/2012	182	1.80	NS	2.49	NS
9/10/2012	186	2.14	NS	2.89	NS
9/12/2012	188	4.73	NS	5.66	NS
9/20/2012	196	2.53	NS	3.63	NS
9/24/2012	200	2.32	NS	2.08	NS
9/26/2012	202	1.75	NS	2.31	NS
10/2/2012	208	2.39	NS	2.79	NS
10/4/2012	210	2.19	NS	2.94	NS
10/10/2012	216	2.24	NS	3.15	NS
10/11/2012	217	1.30	NS	2.38	NS
10/15/2012	221	2.36	NS	3.08	NS
10/17/2012	223	2.39	NS	3.33	NS
10/22/2012	228	1.35	NS	2.47	NS
10/24/2012	230	2.60	NS	3.46	NS
10/29/2012	235	2.42	NS	3.53	NS
11/5/2012	242	2.10	NS	2.58	NS
11/7/2012	244	2.20	NS	2.79	NS
11/12/2012	249	2.49	NS	3.10	NS
11/14/2012	251	2.41	NS	2.92	NS
11/19/2012	256	2.28	NS	2.82	NS
11/26/2012	263	2.22	NS	2.65	NS
11/28/2012	265	2.02	NS	2.70	NS
12/3/2012	270	2.47	NS	3.06	NS
12/5/2012	272	2.23	NS	2.38	NS
12/10/2012	277	2.16	NS	2.26	NS
12/12/2012	279	2.22	NS	2.35	NS
12/17/2012	284	1.97	NS	2.13	NS
12/19/2012	286	1.96	NS	2.44	NS
1/22/2013	320	4.82	NS	5.46	NS
1/24/2013	322	4.97	NS	5.62	NS
1/28/2013	326	2.48	NS	2.61	NS
1/30/2013	328	2.72	NS	3.21	NS
2/4/2013	333	2.13	NS	2.62	NS
2/7/2013	336	2.06	NS	2.40	NS
2/11/2013 (1)	257	1.85	NS	1.86	NS
2/28/2013	357	2.09	NS	2.64	NS
3/4/2013	361	1.84	NS	2.34	NS
3/6/2013	363	1.92	NS	2.63	NS
3/13/2013	370	2.36	NS	2.65	NS
3/14/2013	371	2.34	NS	2.94	NS
3/18/2013	375	2.32	NS	3.13	NS
3/20/2013	377	2.31	NS	2.97	NS

NS - Not Sampled

(1) Infuent from before FCV-104

Concentration of ethene (μg/L) in the influent groundwater and effluent from the FBR.

	Days		Influent		Influent (V-135)		Effluent (after SRT)		Effluent (V-149)
4/5/2012	27	U	5.0		NS	U	5.0		NS
4/10/2012	33	U	5.0		NS	U	5.0		NS
6/6/2012	90	U	5.0		NS	U	5.0		NS
6/11/2012	95	U	5.0		NS	U	5.0	U	5.0
6/13/2012	97	U	5.0		NS	U	5.0	U	5.0
6/18/2012	102	U	5.0		NS	U	5.0	U	5.0
6/20/2012	104	U	5.0		NS	U	5.0	U	5.0
6/25/2012	109	U	5.0		NS	U	5.0	U	5.0
6/27/2012	111	U	5.0		NS	U	5.0		NS
7/3/2012	117		NS	U	5.0	U	5.0		NS
7/5/2012	119		NS	U	5.0	U	5.0		NS
7/9/2012	121		NS	U	5.0	U	5.0		NS
7/11/2012	125		NS	U	5.0	U	5.0		NS
7/16/2012	130		NS	U	5.0	U	5.0		NS
7/31/2012	145		NS	U	5.0	U	5.0		NS
8/2/2012	145		NS	U	5.0	U	5.0		NS
8/6/2012	151		NS	U	5.0	U	5.0		NS
8/8/2012	153		NS	U	5.0	U	5.0		NS
8/13/2012	158		NS	U	5.0	U	5.0		NS
8/16/2012	161		NS	U	5.0	U	5.0		NS
8/20/2012	165		NS	U	5.0	U	5.0		NS
8/22/2012	167		NS	U	5.0	U	5.0		NS
8/27/2012	172		NS	U	5.0	U	5.0		NS
8/30/2012	175		NS	U	5.0	U	5.0		NS
9/5/2012	181		NS	U	5.0	U	5.0		NS
9/6/2012	182		NS	U	5.0	U	5.0		NS
9/10/2012	186		NS	U	5.0	U	5.0		NS
9/12/2012	188		NS	U	5.0	U	5.0		NS
9/20/2012	196		NS	U	5.0	U	5.0		NS
9/24/2012	200		NS	U	5.0	U	5.0		NS
9/26/2012	202		NS	U	5.0	U	5.0		NS
10/2/2012	208		NS	U	5.0	U	5.0		NS
10/4/2012	210		NS	U	5.0	U	5.0		NS
10/10/2012	216		NS	U	5.0	U	5.0		NS
10/11/2012	217		NS	U	5.0	U	5.0		NS
10/15/2012	221		NS	U	5.0	U	5.0		NS
10/17/2012	223		NS	U	5.0	U	5.0		NS
10/22/2012	228		NS	U	5.0	U	5.0		NS
10/24/2012	230		NS	U	5.0	U	5.0		NS
10/29/2012	235		NS	U	5.0	U	5.0		NS
11/5/2012	242		NS	U	5.0	U	5.0		NS
11/7/2012	244		NS	U	5.0	U	5.0		NS
11/12/2012	249		NS	U	5.0	U	5.0		NS
11/14/2012	251		NS	U	5.0	U	5.0		NS
11/19/2012	256		NS	U	5.0	U	5.0		NS
11/26/2012	263		NS	U	5.0	U	5.0		NS
11/28/2012	265		NS	U	5.0	U	5.0		NS
12/3/2012	270		NS	U	5.0	U	5.0		NS
12/5/2012	272		NS	U	5.0	U	5.0		NS
12/10/2012	277		NS	U	5.0	U	5.0		NS
12/12/2012	279		NS	U	5.0	U	5.0		NS
12/17/2012	284		NS	U	5.0	U	5.0		NS
12/19/2012	286		NS	U	5.0	U	5.0		NS
1/22/2013	320		NS	U	5.0	U	5.0		NS
1/24/2013	322		NS	U	5.0	U	5.0		NS
1/28/2013	326		NS	U	5.0	U	5.0		NS
1/30/2013	328		NS	U	5.0	U	5.0		NS
2/4/2013	333		NS	U	5.0	U	5.0		NS
2/7/2013	336		NS	U	5.0	U	5.0		NS
2/11/2013	257		NS	U	5.0	U	5.0		NS
2/28/2013	357		NS	U	5.0	U	5.0		NS
3/4/2013	361		NS	U	5.0	U	5.0		NS
3/6/2013	363		NS	U	5.0	U	5.0		NS
3/13/2013	370		NS	U	5.0	U	5.0		NS
3/14/2013	371		NS	U	5.0	U	5.0		NS
3/18/2013	375		NS	U	5.0	U	5.0		NS
3/20/2013	377		NS	U	5.0	U	5.0		NS

NS - Not Sampled

U - The compound was not detected at the indicated PQL

Concentration of ethane (μg/L) in the influent groundwater and effluent from the FBR.

					(V-135)		(after SRT)		(V-149)
	Days		Influent		Influent		Effluent		Effluent
4/5/2012	27	U	4.0		NS	U	4.0		NS
4/10/2012	33	U	4.0		NS	U	4.0		NS
6/6/2012	90	U	4.0		NS	U	4.0		NS
6/11/2012	95	U	4.0		NS	U	4.0	U	4.0
6/13/2012	97	U	4.0		NS	U	4.0	U	4.0
6/18/2012	102	U	4.0		NS	U	4.0	U	4.0
6/20/2012	104	U	4.0		NS	U	4.0	U	4.0
6/25/2012	109	U	4.0		NS	U	4.0	U	4.0
6/27/2012	111	J	2.56		NS	U	4.0		NS
7/3/2012	117		NS	J	2.81	U	4.0		NS
7/5/2012	119		NS	J	2.60	U	4.0		NS
7/9/2012	121		NS	J	2.63	U	4.0		NS
7/11/2012	125		NS	J	1.85	U	4.0		NS
7/16/2012	130		NS	J	2.32	U	4.0		NS
7/31/2012	145		NS	J	1.71	U	4.0		NS
8/2/2012	145		NS	J	1.65	U	4.0		NS
8/6/2012	151		NS	J	2.08	U	4.0		NS
8/8/2012	153		NS	J	1.91	U	4.0		NS
8/13/2012	158		NS	J	1.75	U	4.0		NS
8/16/2012	161		NS	U	4.0	U	4.0		NS
8/20/2012	165		NS	J	1.83	U	4.0		NS
8/22/2012	167		NS	U	4.0	U	4.0		NS
8/27/2012	172		NS	U	4.0	U	4.0		NS
8/30/2012	175		NS	U	4.0	U	4.0		NS
9/5/2012	181		NS	U	4.0	U	4.0		NS
9/6/2012	182		NS	U	4.0	U	4.0		NS
9/10/2012	186		NS	U	4.0	U	4.0		NS
9/12/2012	188		NS	U	4.0	U	4.0		NS
9/20/2012	196		NS	U	4.0	U	4.0		NS
9/24/2012	200		NS	U	4.0	U	4.0		NS
9/26/2012	202		NS	U	4.0	U	4.0		NS
10/2/2012	208		NS	U	4.0	U	4.0		NS
10/4/2012	210		NS	U	4.0	U	4.0		NS
10/10/2012	216		NS	U	4.0	U	4.0		NS
10/11/2012	217		NS	U	4.0	U	4.0		NS
10/15/2012	221		NS	U	4.0	U	4.0		NS
10/17/2012	223		NS	U	4.0	U	4.0		NS
10/22/2012	228		NS	U	4.0	U	4.0		NS
10/24/2012	230		NS	U	4.0	U	4.0		NS
10/29/2012	235		NS	U	4.0	U	4.0		NS
11/5/2012	242		NS	U	4.0	U	4.0		NS
11/7/2012	244		NS	U	4.0	U	4.0		NS
11/12/2012	249		NS	J	3.80	U	4.0		NS
11/14/2012	251		NS		6.99	U	4.0		NS
11/19/2012	256		NS		4.72	U	4.0		NS
11/26/2012	263		NS	J	3.72	U	4.0		NS
11/28/2012	265		NS	J	3.15	U	4.0		NS
12/3/2012	270		NS	J	2.36	U	4.0		NS
12/5/2012	272		NS	U	4.0	U	4.0		NS
12/10/2012	277		NS	U	4.0	U	4.0		NS
12/12/2012	279		NS	U	4.0	U	4.0		NS
12/17/2012	284		NS	J	2.20	U	4.0		NS
12/19/2012	286		NS	J	2.92	U	4.0		NS
1/22/2013	320		NS	J	2.20	J	2.20		NS
1/24/2013	322		NS	J	2.20	J	2.20		NS
1/28/2013	326		NS	J	2.20	J	2.20		NS
1/30/2013	328		NS	J	2.20	J	2.20		NS
2/4/2013	333		NS	U	4.0	U	4.0		NS
2/7/2013	336		NS	U	4.0	U	4.0		NS
2/11/2013	257		NS	U	4.0	U	4.0		NS
2/28/2013	357		NS	U	4.0	U	4.0		NS
3/4/2013	361		NS	U	4.0	U	4.0		NS
3/6/2013	363		NS	U	4.0	U	4.0		NS
3/13/2013	370		NS	U	4.0	U	4.0		NS
3/14/2013	371		NS	U	4.0	U	4.0		NS
3/18/2013	375		NS	U	4.0	U	4.0		NS
3/20/2013	377		NS	U	4.0	U	4.0		NS

NS - Not Sampled

U - The compound was not detected at the indicated PQL

J - The compound was detected at a level below the method PQL. The value reported is an estimated value.

Concentration of methane (μg/L) in the influent groundwater and effluent from the FBR.

					(V-135)		(after SRT)		(V-149)
	Days		Influent		Influent		Effluent		Effluent
4/5/2012	27	J	0.48		NS	J	0.48		NS
4/10/2012	33	J	0.55		NS	J	0.57		NS
6/6/2012	90	U	2.0		NS	J	0.55		NS
6/11/2012	95	U	2.0		NS	U	2.0	U	2.0
6/13/2012	97	U	2.0		NS	U	2.0	U	2.0
6/18/2012	102	U	2.0		NS	U	2.0	U	2.0
6/20/2012	104	U	2.0		NS	U	2.0	U	2.0
6/25/2012	109	U	2.0		NS	U	2.0	U	2.0
6/27/2012	111	U	2.0		NS	U	2.0		NS
7/3/2012	117		NS	U	2.0	U	2.0		NS
7/5/2012	119		NS	U	2.0	U	2.0		NS
7/9/2012	121		NS	U	2.0	U	2.0		NS
7/11/2012	125		NS	U	2.0	U	2.0		NS
7/16/2012	130		NS	U	2.0	U	2.0		NS
7/31/2012	145		NS	J	0.44	U	2.0		NS
8/2/2012	145		NS	J	0.52	U	2.0		NS
8/6/2012	151		NS	U	2.0	U	2.0		NS
8/8/2012	153		NS		118	U	2.0		NS
8/13/2012	158		NS	U	2.0	U	2.0		NS
8/16/2012	161		NS	U	2.0	U	2.0		NS
8/20/2012	165		NS	U	2.0	U	2.0		NS
8/22/2012	167		NS	U	2.0	U	2.0		NS
8/27/2012	172		NS	U	2.0	U	2.0		NS
8/30/2012	175		NS	U	2.0	U	2.0		NS
9/5/2012	181		NS	U	2.0	U	2.0		NS
9/6/2012	182		NS	U	2.0	U	2.0		NS
9/10/2012	186		NS	U	2.0	U	2.0		NS
9/12/2012	188		NS	U	2.0	U	2.0		NS
9/20/2012	196		NS	U	2.0	U	2.0		NS
9/24/2012	200		NS	U	2.0	U	2.0		NS
9/26/2012	202		NS	U	2.0	U	2.0		NS
10/2/2012	208		NS	U	2.0	U	2.0		NS
10/4/2012	210		NS	U	2.0	U	2.0		NS
10/10/2012	216		NS	U	2.0	U	2.0		NS
10/11/2012	217		NS	U	2.0	U	2.0		NS
10/15/2012	221		NS	U	2.0	U	2.0		NS
10/17/2012	223		NS	U	2.0	U	2.0		NS
10/22/2012	228		NS	U	2.0	U	2.0		NS
10/24/2012	230		NS	U	2.0	U	2.0		NS
10/29/2012	235		NS	U	2.0	U	2.0		NS
11/5/2012	242		NS	U	2.0	U	2.0		NS
11/7/2012	244		NS	U	2.0	U	2.0		NS
11/12/2012	249		NS	U	2.0	U	2.0		NS
11/14/2012	251		NS	U	2.0	U	2.0		NS
11/19/2012	256		NS	U	2.0	U	2.0		NS
11/26/2012	263		NS	U	2.0	U	2.0		NS
11/28/2012	265		NS	U	2.0	U	2.0		NS
12/3/2012	270		NS	U	2.0	U	2.0		NS
12/5/2012	272		NS	U	2.0	U	2.0		NS
12/10/2012	277		NS	J	1.02	J	1.02		NS
12/12/2012	279		NS	J	0.78	J	1.19		NS
12/17/2012	284		NS	U	2.0	U	2.0		NS
12/19/2012	286		NS	U	2.0	U	2.0		NS
1/22/2013	320		NS	U	2.0	U	2.0		NS
1/24/2013	322		NS	U	2.0	U	2.0		NS
1/28/2013	326		NS	U	2.0	U	2.0		NS
1/30/2013	328		NS	U	2.0	U	2.0		NS
2/4/2013	333		NS	U	2.0	U	2.0		NS
2/7/2013	336		NS	U	2.0	U	2.0		NS
2/11/2013	257		NS	U	2.0	U	2.0		NS
2/28/2013	357		NS	U	2.0	U	2.0		NS
3/4/2013	361		NS	U	2.0	U	2.0		NS
3/6/2013	363		NS	U	2.0	U	2.0		NS
3/13/2013	370		NS	U	2.0	U	2.0		NS
3/14/2013	371		NS	U	2.0	U	2.0		NS
3/18/2013	375		NS	U	2.0	U	2.0		NS
3/20/2013	377		NS	U	2.0	U	2.0		NS

NS - Not Sampled

U - The compound was not detected at the indicated PQL

J - The compound was detected at a level below the method PQL. The value reported is an estimated value.

Concentration of bromide (mg/L) in the influent groundwater and effluent from the FBR.

	Days		Influent		(V-135) Influent		(after SRT) Effluent		(V-149) Effluent
4/5/2012	27		0.31		NS		0.24		NS
4/10/2012	33		0.39		NS		0.35		NS
6/6/2012	90		0.24		NS		0.29		NS
6/11/2012	95		0.29		NS		0.32		NS
6/13/2012	97		0.32		NS		0.36		NS
6/18/2012	102		0.42		NS		0.76		NS
6/20/2012	104		0.72		NS		0.70		NS
6/25/2012	109		0.46		NS		0.39		NS
6/27/2012	111		0.38		NS		0.31		NS
7/3/2012	117		0.68		NS		0.47		NS
7/5/2012	119		0.44		NS		0.35		NS
7/9/2012	121		0.39		NS		0.35		NS
7/11/2012	125		0.37		NS		0.23		NS
7/16/2012	130		0.30		NS	J	0.17		NS
7/30/2012	144		0.44		NS		0.33		NS
8/2/2012	145		0.38		NS		0.33		NS
8/6/2012	151		0.43		NS		0.29		NS
8/8/2012	153		0.40		NS		0.40		NS
8/13/2012	158	J	0.18		NS	U	0.20		NS
8/16/2012	161	J	0.18		NS	J	0.17		NS
8/20/2012	165		0.50		NS		0.37		NS
8/22/2012	167		0.38		NS		0.47		NS
8/27/2012	172		0.34		NS	J	0.18		NS
8/30/2012	175	J	0.14		NS	J	0.16		NS
9/5/2012	181		0.37		NS		0.40		NS
9/6/2012	182		0.42		NS		0.38		NS
9/10/2012	186		0.31		NS		0.49		NS
9/12/2012	188		0.46		NS		0.53		NS
9/20/2012	196		0.99		NS		0.27		NS
9/24/2012	200		0.33		NS		0.66		NS
9/26/2012	202		0.42		NS		0.39		NS
10/2/2012	208	J	0.17		NS		0.20		NS
10/4/2012	210	J	0.18		NS	J	0.19		NS
10/10/2012	216	J	0.18		NS		0.41		NS
10/11/2012	217	J	0.12		NS		0.25		NS
10/15/2012	221		0.44		NS		0.65		NS
10/17/2012	223		0.29		NS		0.37		NS
10/22/2012	228		0.29		NS		0.41		NS
10/24/2012	230		0.32		NS		0.57		NS
10/29/2012	235		0.29		NS		0.28		NS
11/5/2012	242		0.26		NS		0.23		NS
11/7/2012	244		0.27		NS		0.26		NS
11/12/2012	249		0.41		NS		0.33		NS
11/14/2012	251		0.41		NS		0.50		NS
11/19/2012	256		0.22		NS		0.30		NS
11/26/2012	263		0.21		NS		0.48		NS
11/28/2012	265		0.28		NS		0.39		NS
12/3/2012	270		0.50		NS		0.44		NS
12/5/2012	272		0.44		NS		0.49		NS
12/10/2012	277		0.55		NS		0.63		NS
12/12/2012	279		0.47		NS		0.47		NS
12/17/2012	284	U	0.2		NS	U	0.2		NS
12/19/2012	286	U	0.2		NS	U	0.2		NS
1/22/2013	320	U	0.2		NS	U	0.2		NS
1/24/2013	322	U	0.2		NS	U	0.2		NS
1/28/2013	326	U	0.2		NS	U	0.2		NS
1/30/2013	328	U	0.2		NS	U	0.2		NS
2/4/2013	333	U	0.2		NS	U	0.2		NS
2/7/2013	336	U	0.2		NS	U	0.2		NS
2/11/2013 (1)	257	U	0.2		NS	U	0.2		NS
2/28/2013	357	U	0.2		NS	U	0.2		NS
3/4/2013	361	U	0.2		NS	U	0.2		NS
3/6/2013	363	U	0.2		NS	U	0.2		NS
3/13/2013	370	U	0.2		NS	U	0.2		NS
3/14/2013	371	U	0.2		NS	U	0.2		NS
3/18/2013	375	U	0.2		NS	U	0.2		NS
3/20/2013	377	U	0.2		NS	U	0.2		NS

NS - Not Sampled

U - The compound was not detected at the indicated PQL

J - The compound was detected at a level below the method PQL. The value reported is an estimated value.

(1) Infuent from before FCV-104

Concentration of sulfate (mg/L) in the influent groundwater and effluent from the FBR.

	Days	Influent	(V-135) Influent	(after SRT) Effluent	(V-149) Effluent
4/5/2012	27	214	NS	222	NS
4/10/2012	33	207	NS	209	NS
6/6/2012	90	184	NS	186	NS
6/11/2012	95	212	NS	208	NS
6/13/2012	97	217	NS	210	NS
6/18/2012	102	205	NS	208	NS
6/20/2012	104	206	NS	209	NS
6/25/2012	109	210	NS	217	NS
6/27/2012	111	213	NS	217	NS
7/3/2012	117	214	NS	216	NS
7/5/2012	119	220	NS	222	NS
7/9/2012	121	220	NS	218	NS
7/11/2012	125	215	NS	218	NS
7/16/2012	130	234	NS	231	NS
7/30/2012	144	230	NS	238	NS
8/2/2012	145	250	NS	289	NS
8/6/2012	151	233	NS	236	NS
8/8/2012	153	308	NS	326	NS
8/13/2012	158	237	NS	232	NS
8/16/2012	161	235	NS	234	NS
8/20/2012	165	246	NS	235	NS
8/22/2012	167	234	NS	235	NS
8/27/2012	172	240	NS	235	NS
8/30/2012	175	230	NS	232	NS
9/5/2012	181	234	NS	237	NS
9/6/2012	182	227	NS	230	NS
9/10/2012	186	241	NS	240	NS
9/12/2012	188	336	NS	331	NS
9/20/2012	196	257	NS	260	NS
9/24/2012	200	253	NS	251	NS
9/26/2012	202	270	NS	268	NS
10/2/2012	208	254	NS	249	NS
10/4/2012	210	247	NS	250	NS
10/10/2012	216	246	NS	249	NS
10/11/2012	217	208	NS	209	NS
10/15/2012	221	225	NS	227	NS
10/17/2012	223	224	NS	228	NS
10/22/2012	228	200	NS	200	NS
10/24/2012	230	243	NS	245	NS
10/29/2012	235	234	NS	237	NS
11/5/2012	242	248	NS	249	NS
11/7/2012	244	246	NS	249	NS
11/12/2012	249	255	NS	256	NS
11/14/2012	251	251	NS	251	NS
11/19/2012	256	244	NS	248	NS
11/26/2012	263	247	NS	250	NS
11/28/2012	265	260	NS	257	NS
12/3/2012	270	247	NS	247	NS
12/5/2012	272	249	NS	250	NS
12/10/2012	277	244	NS	245	NS
12/12/2012	279	248	NS	249	NS
12/17/2012	284	292	NS	198	NS
12/19/2012	286	295	NS	298	NS
1/22/2013	320	343	NS	339	NS
1/24/2013	322	342	NS	330	NS
1/28/2013	326	265	NS	271	NS
1/30/2013	328	273	NS	277	NS
2/4/2013	333	238	NS	239	NS
2/7/2013	336	248	NS	261	NS
2/11/2013 (1)	257	246	NS	254	NS
2/28/2013	357	265	NS	265	NS
3/4/2013	361	260	NS	261	NS
3/6/2013	363	254	NS	260	NS
3/13/2013	370	267	NS	263	NS
3/14/2013	371	254	NS	257	NS
3/18/2013	375	247	NS	254	NS
3/20/2013	377	252	NS	250	NS

NS - Not Sampled

(1) Infuent from before FCV-104

Concentration of nitrite-N (mg/L) in the influent groundwater and effluent from the FBR.

					(V-135)		(after SRT)		(V-149)
	Days		Influent		Influent		Effluent		Effluent
4/5/2012	27	U	0.2		NS	U	0.2		NS
4/10/2012	33	U	0.2		NS	U	0.2		NS
6/6/2012	90	U	0.2		NS	U	0.2		NS
6/11/2012	95	U	0.2		NS	U	0.2		NS
6/13/2012	97	U	0.2		NS	U	0.2		NS
6/18/2012	102	U	0.2		NS	U	0.2		NS
6/20/2012	104	U	0.2		NS	U	0.2		NS
6/25/2012	109	U	0.2		NS	U	0.2		NS
6/27/2012	111	U	0.2		NS	U	0.2		NS
7/3/2012	117	U	0.2		NS	U	0.2		NS
7/5/2012	119	U	0.2		NS	U	0.2		NS
7/9/2012	121	U	0.2		NS	U	0.2		NS
7/11/2012	125	U	0.2		NS	U	0.2		NS
7/16/2012	130	U	0.2		NS	U	0.2		NS
7/30/2012	144	U	0.2		NS	U	0.2		NS
8/2/2012	145	U	0.2		NS	U	0.2		NS
8/6/2012	151	U	0.2		NS	U	0.2		NS
8/8/2012	153	U	0.2		NS	U	0.2		NS
8/13/2012	158	U	0.2		NS	U	0.2		NS
8/16/2012	161	U	0.2		NS	U	0.2		NS
8/20/2012	165	U	0.2		NS	U	0.2		NS
8/22/2012	167	U	0.2		NS	U	0.2		NS
8/27/2012	172	U	0.2		NS	U	0.2		NS
8/30/2012	175	U	0.2		NS	U	0.2		NS
9/5/2012	181	U	0.2		NS	U	0.2		NS
9/6/2012	182	U	0.2		NS	U	0.2		NS
9/10/2012	186	U	0.2		NS	U	0.2		NS
9/12/2012	188	U	0.2		NS	U	0.2		NS
9/20/2012	196	U	0.2		NS	U	0.2		NS
9/24/2012	200	U	0.2		NS	U	0.2		NS
9/26/2012	202	U	0.2		NS	U	0.2		NS
10/2/2012	208	U	0.2		NS	U	0.2		NS
10/4/2012	210	U	0.2		NS	U	0.2		NS
10/10/2012	216	U	0.2		NS	U	0.2		NS
10/11/2012	217	U	0.2		NS	U	0.2		NS
10/15/2012	221	U	0.2		NS	U	0.2		NS
10/17/2012	223	U	0.2		NS	U	0.2		NS
10/22/2012	228	U	0.2		NS	U	0.2		NS
10/24/2012	230	U	0.2		NS	U	0.2		NS
10/29/2012	235	U	0.2		NS	U	0.2		NS
11/5/2012	242	U	0.2		NS	U	0.2		NS
11/7/2012	244	U	0.2		NS	U	0.2		NS
11/12/2012	249	U	0.2		NS	U	0.2		NS
11/14/2012	251	U	0.2		NS	U	0.2		NS
11/19/2012	256	U	0.2		NS	U	0.2		NS
11/26/2012	263	U	0.2		NS	U	0.2		NS
11/28/2012	265	U	0.2		NS	U	0.2		NS
12/3/2012	270	U	0.2		NS	U	0.2		NS
12/5/2012	272	U	0.2		NS	U	0.2		NS
12/10/2012	277	U	0.2		NS	U	0.2		NS
12/12/2012	279	U	0.2		NS	U	0.2		NS
12/17/2012	284	U	0.2		NS	U	0.2		NS
12/19/2012	286	U	0.2		NS	U	0.2		NS
1/22/2013	320	U	0.2		NS	U	0.2		NS
1/24/2013	322	U	0.2		NS	U	0.2		NS
1/28/2013	326	U	0.2		NS	U	0.2		NS
1/30/2013	328	U	0.2		NS	U	0.2		NS
2/4/2013	333	U	0.2		NS	U	0.2		NS
2/7/2013	336	U	0.2		NS	U	0.2		NS
2/11/2013 (1)	257	U	0.2		NS	U	0.2		NS
2/28/2013	357	U	0.2		NS	U	0.2		NS
3/4/2013	361	U	0.2		NS	U	0.2		NS
3/6/2013	363	U	0.2		NS	U	0.2		NS
3/13/2013	370	U	0.2		NS	U	0.2		NS
3/14/2013	371	U	0.2		NS	U	0.2		NS
3/18/2013	375	U	0.2		NS	U	0.2		NS
3/20/2013	377	U	0.2		NS	U	0.2		NS

NS - Not Sampled

U - The compound was not detected at the indicated PQL

(1) Infuent from before FCV-104

Concentration of chloride (mg/L) in the influent groundwater and effluent from the FBR.

			(V-135)	(after SRT)	(V-149)
	Days	Influent	Influent	Effluent	Effluent
4/5/2012	27	30.0	NS	29.5	NS
4/10/2012	33	29.3	NS	29.5	NS
6/6/2012	90	25.9	NS	47.6	NS
6/11/2012	95	29.0	NS	28.8	NS
6/13/2012	97	29.9	NS	29.1	NS
6/18/2012	102	28.7	NS	29.0	NS
6/20/2012	104	29.1	NS	29.2	NS
6/25/2012	109	30.8	NS	31.3	NS
6/27/2012	111	29.8	NS	31.4	NS
7/3/2012	117	33.8	NS	30.3	NS
7/5/2012	119	31.2	NS	31.5	NS
7/9/2012	121	30.3	NS	30.0	NS
7/11/2012	125	29.6	NS	30.1	NS
7/16/2012	130	36.8	NS	34.9	NS
7/30/2012	144	32.1	NS	35.6	NS
8/2/2012	145	36.1	NS	41.2	NS
8/6/2012	151	32.5	NS	34.0	NS
8/8/2012	153	45.2	NS	47.6	NS
8/13/2012	158	34.7	NS	34.0	NS
8/16/2012	161	34.8	NS	34.8	NS
8/20/2012	165	35.7	NS	34.1	NS
8/22/2012	167	34.1	NS	35.0	NS
8/27/2012	172	35.0	NS	34.2	NS
8/30/2012	175	33.7	NS	34.0	NS
9/5/2012	181	34.1	NS	33.7	NS
9/6/2012	182	33.0	NS	33.6	NS
9/10/2012	186	34.8	NS	34.8	NS
9/12/2012	188	49.6	NS	49.5	NS
9/20/2012	196	38.0	NS	39.1	NS
9/24/2012	200	36.1	NS	36.2	NS
9/26/2012	202	46.6	NS	47.3	NS
10/2/2012	208	35.8	NS	35.1	NS
10/4/2012	210	35.7	NS	36.2	NS
10/10/2012	216	35.3	NS	36.0	NS
10/11/2012	217	30.8	NS	30.0	NS
10/15/2012	221	37.5	NS	37.4	NS
10/17/2012	223	36.3	NS	37.1	NS
10/22/2012	228	31.7	NS	32.2	NS
10/24/2012	230	39.0	NS	39.1	NS
10/29/2012	235	36.4	NS	36.8	NS
11/5/2012	242	38.7	NS	38.9	NS
11/7/2012	244	39.4	NS	39.3	NS
11/12/2012	249	41.4	NS	42.1	NS
11/14/2012	251	41.4	NS	40.3	NS
11/19/2012	256	40.1	NS	40.1	NS
11/26/2012	263	40.8	NS	40.7	NS
11/28/2012	265	47.3	NS	45.5	NS
12/3/2012	270	41.1	NS	41.4	NS
12/5/2012	272	41.6	NS	41.5	NS
12/10/2012	277	39.9	NS	40.5	NS
12/12/2012	279	40.9	NS	40.8	NS
12/17/2012	284	41.5	NS	42.1	NS
12/19/2012	286	41.6	NS	41.8	NS
1/22/2013	320	51.2	NS	51.8	NS
1/24/2013	322	51.4	NS	49.9	NS
1/28/2013	326	39.3	NS	39.7	NS
1/30/2013	328	40.4	NS	40.3	NS
2/4/2013	333	31.7	NS	31.6	NS
2/7/2013	336	31.4	NS	31.8	NS
2/11/2013 (1)	257	31.4	NS	31.2	NS
2/28/2013	357	33.9	NS	34.0	NS
3/4/2013	361	33.1	NS	33.4	NS
3/6/2013	363	32.6	NS	33.3	NS
3/13/2013	370	39.5	NS	39.2	NS
3/14/2013	371	38.0	NS	38.8	NS
3/18/2013	375	36.6	NS	38.2	NS
3/20/2013	377	38.2	NS	37.6	NS

NS - Not Sampled

(1) Infuent from before FCV-104

Concentration of floride (mg/L) in the influent groundwater and effluent from the FBR.

			(V-135)	(after SRT)	(V-149)
	Days	Influent	Influent	Effluent	Effluent
4/5/2012	27	0.50	NS	0.53	NS
4/10/2012	33	0.45	NS	0.53	NS
6/6/2012	90	0.59	NS	0.47	NS
6/11/2012	95	0.49	NS	0.43	NS
6/13/2012	97	0.53	NS	0.63	NS
6/18/2012	102	0.59	NS	0.43	NS
6/20/2012	104	0.40	NS	0.51	NS
6/25/2012	109	0.67	NS	0.61	NS
6/27/2012	111	0.59	NS	0.64	NS
7/3/2012	117	0.41	NS	0.38	NS
7/5/2012	119	0.42	NS	0.46	NS
7/9/2012	121	0.54	NS	0.47	NS
7/11/2012	125	0.40	NS	0.47	NS
7/16/2012	130	0.54	NS	0.60	NS
7/30/2012	144	0.63	NS	0.59	NS
8/2/2012	145	0.64	NS	0.65	NS
8/6/2012	151	0.49	NS	0.48	NS
8/8/2012	153	0.85	NS	0.82	NS
8/13/2012	158	0.64	NS	0.63	NS
8/16/2012	161	0.63	NS	0.69	NS
8/20/2012	165	0.62	NS	0.59	NS
8/22/2012	167	0.61	NS	0.70	NS
8/27/2012	172	0.67	NS	0.63	NS
8/30/2012	175	0.64	NS	0.58	NS
9/5/2012	181	0.64	NS	0.65	NS
9/6/2012	182	0.65	NS	0.66	NS
9/10/2012	186	0.65	NS	0.63	NS
9/12/2012	188	0.94	NS	0.86	NS
9/20/2012	196	0.70	NS	0.70	NS
9/24/2012	200	0.71	NS	0.64	NS
9/26/2012	202	0.60	NS	0.56	NS
10/2/2012	208	0.62	NS	0.68	NS
10/4/2012	210	0.60	NS	0.60	NS
10/10/2012	216	0.65	NS	0.60	NS
10/11/2012	217	0.57	NS	0.60	NS
10/15/2012	221	0.64	NS	0.65	NS
10/17/2012	223	0.43	NS	0.61	NS
10/22/2012	228	0.59	NS	0.59	NS
10/24/2012	230	0.48	NS	0.71	NS
10/29/2012	235	0.63	NS	0.70	NS
11/5/2012	242	0.69	NS	0.68	NS
11/7/2012	244	0.59	NS	0.70	NS
11/12/2012	249	0.85	NS	0.74	NS
11/14/2012	251	0.79	NS	0.79	NS
11/19/2012	256	0.58	NS	0.61	NS
11/26/2012	263	0.79	NS	0.76	NS
11/28/2012	265	0.73	NS	0.81	NS
12/3/2012	270	0.73	NS	0.82	NS
12/5/2012	272	0.72	NS	0.78	NS
12/10/2012	277	0.73	NS	0.71	NS
12/12/2012	279	0.72	NS	0.79	NS
12/17/2012	284	0.46	NS	0.46	NS
12/19/2012	286	0.46	NS	0.46	NS
1/22/2013	320	1.00	NS	1.00	NS
1/24/2013	322	1.08	NS	1.01	NS
1/28/2013	326	0.76	NS	0.83	NS
1/30/2013	328	0.82	NS	0.86	NS
2/4/2013	333	0.54	NS	0.54	NS
2/7/2013	336	0.54	NS	0.51	NS
2/11/2013 (1)	257	0.62	NS	0.68	NS
2/28/2013	357	0.51	NS	0.49	NS
3/4/2013	361	0.49	NS	0.56	NS
3/6/2013	363	0.61	NS	0.62	NS
3/13/2013	370	0.68	NS	0.62	NS
3/14/2013	371	0.64	NS	0.67	NS
3/18/2013	375	0.76	NS	0.86	NS
3/20/2013	377	0.83	NS	0.83	NS

NS - Not Sampled

U - The compound was not detected at the indicated PQL

J - The compound was detected at a level below the method PQL. The value reported is an estimated value.

(1) Infuent from before FCV-104

Concentration of trichloroethene (μg/L) in the influent groundwater and effluent from the FBR.

	Days		Influent		(V-135) Influent		(after SRT) Effluent		(V-149) Effluent
4/5/2012	27		24.0		NS	U	5.0		NS
4/10/2012	33	U	5.0		NS	U	5.0		NS
6/6/2012	90	U	5.0		NS	U	5.0		NS
6/11/2012	95	U	5.0		NS	U	5.0	U	5.0
6/13/2012	97	U	5.0		NS	U	5.0	U	5.0
6/18/2012	102	U	5.0		NS	U	5.0	U	5.0
6/20/2012	104	U	5.0		NS	U	5.0	U	5.0
6/25/2012	109	U	5.0		NS	U	5.0	U	5.0
6/27/2012	111	U	5.0		NS	U	5.0		NS
7/3/2012	117	U	5.0		NS	U	5.0		NS
7/5/2012	119	U	5.0		NS	U	5.0		NS
7/9/2012	121	U	5.0		NS	U	5.0		NS
7/11/2012	125	U	5.0		NS	U	5.0		NS
7/16/2012	130	U	5.0		NS	U	5.0		NS
7/30/2012	144	U	5.0		NS	U	5.0		NS
8/2/2012	145	U	5.0		NS	U	5.0		NS
8/6/2012	151	U	5.0		NS	U	5.0		NS
8/8/2012	153	U	5.0		NS	U	5.0		NS
8/13/2012	158	U	5.0		NS	U	5.0		NS
8/16/2012	161	U	5.0		NS	U	5.0		NS
8/20/2012	165	U	5.0		NS	U	5.0		NS
8/22/2012	167	U	5.0		NS	U	5.0		NS
8/27/2012	172	U	5.0		NS	U	5.0		NS
8/30/2012	175	U	5.0		NS	U	5.0		NS
9/5/2012	181	U	5.0		NS	U	5.0		NS
9/6/2012	182	U	5.0		NS	U	5.0		NS
9/10/2012	186	U	5.0		NS	U	5.0		NS
9/20/2012	196	U	5.0		NS	U	5.0		NS
9/24/2012	200	U	5.0		NS	U	5.0		NS
10/2/2012	208	U	5.0		NS	U	5.0		NS
10/10/2012	216	U	5.0		NS	U	5.0		NS
10/15/2012	221	U	5.0		NS	U	5.0		NS
10/22/2012	228	U	5.0		NS	U	5.0		NS
10/29/2012	235	U	5.0		NS	U	5.0		NS
11/5/2012	242	U	5.0		NS	U	5.0		NS
11/12/2012	249	U	5.0		NS	U	5.0		NS
11/19/2012	256	U	5.0		NS	U	5.0		NS
11/26/2012	263	U	5.0		NS	U	5.0		NS
12/3/2012	270	U	5.0		NS	U	5.0		NS
12/10/2012	277	U	5.0		NS	U	5.0		NS
12/17/2012	284	U	5.0		NS	U	5.0		NS
1/22/2013	320	U	5.0		NS	U	5.0		NS
1/28/2013	326	U	5.0		NS	U	5.0		NS
2/7/2013	336	U	5.0		NS	U	5.0		NS
2/11/2013 (1,2)	257	U	5.0		NS	U	5.0		NS
2/28/2013 (1,2)	357		16.7		NS	J	0.6		NS
3/4/2013 (2)	361		14.8		NS	J	0.9		NS
3/6/2013 (2)	363		15.3		NS	J	0.9		NS
3/13/2013 (2)	370		18.6		NS	J	0.6		NS
3/14/2013 (2)	371		17.4		NS	J	0.6		NS
3/18/2013 (2)	375		14.5		NS	U	5.0		NS
3/20/2013 (2)	377		15.9		NS	J	0.6		NS

NS - Not Sampled

U - The compound was not detected at the indicated PQL

(1) Samples run out of hold

(2) Infuent from before FCV-104

Concentration of trichlorofluoromethane (CFC-11; μg/L) in the influent groundwater and effluent from the FBR.

					(V-135)		(after SRT)		(V-149)
	Days		Influent		Influent		Effluent		Effluent
4/5/2012	27		50.5		NS	U	5.0		NS
4/10/2012	33	U	5.0		NS	U	5.0		NS
6/6/2012	90	U	5.0		NS	U	5.0		NS
6/11/2012	95	U	5.0		NS	U	5.0	U	5.0
6/13/2012	97	U	5.0		NS	U	5.0	U	5.0
6/18/2012	102	U	5.0		NS	U	5.0	U	5.0
6/20/2012	104	U	5.0		NS	U	5.0	U	5.0
6/25/2012	109	U	5.0		NS	U	5.0	U	5.0
6/27/2012	111	U	5.0		NS	U	5.0		NS
7/3/2012	117	U	5.0		NS	U	5.0		NS
7/5/2012	119	U	5.0		NS	U	5.0		NS
7/9/2012	121	U	5.0		NS	U	5.0		NS
7/11/2012	125	U	5.0		NS	U	5.0		NS
7/16/2012	130	U	5.0		NS	U	5.0		NS
7/30/2012	144	U	5.0		NS	U	5.0		NS
8/2/2012	145	U	5.0		NS	U	5.0		NS
8/6/2012	151	U	5.0		NS	U	5.0		NS
8/8/2012	153	U	5.0		NS	U	5.0		NS
8/13/2012	158	U	5.0		NS	U	5.0		NS
8/16/2012	161	U	5.0		NS	U	5.0		NS
8/20/2012	165	U	5.0		NS	U	5.0		NS
8/22/2012	167	U	5.0		NS	U	5.0		NS
8/27/2012	172	U	5.0		NS	U	5.0		NS
8/30/2012	175	U	5.0		NS	U	5.0		NS
9/5/2012	181	U	5.0		NS	U	5.0		NS
9/6/2012	182	U	5.0		NS	U	5.0		NS
9/10/2012	186	U	5.0		NS	U	5.0		NS
9/20/2012	196	U	5.0		NS	U	5.0		NS
9/24/2012	200	U	5.0		NS	U	5.0		NS
10/2/2012	208	U	5.0		NS	U	5.0		NS
10/10/2012	216	U	5.0		NS	U	5.0		NS
10/15/2012	221	U	5.0		NS	U	5.0		NS
10/22/2012	228	U	5.0		NS	U	5.0		NS
10/29/2012	235	U	5.0		NS	U	5.0		NS
11/5/2012	242	U	5.0		NS	U	5.0		NS
11/12/2012	249	U	5.0		NS	U	5.0		NS
11/19/2012	256	U	5.0		NS	U	5.0		NS
11/26/2012	263	U	5.0		NS	U	5.0		NS
12/3/2012	270	U	5.0		NS	U	5.0		NS
12/10/2012	277	U	5.0		NS	U	5.0		NS
12/17/2012	284	U	5.0		NS	U	5.0		NS
1/22/2013	320	U	5.0		NS	U	5.0		NS
1/28/2013	326	U	5.0		NS	U	5.0		NS
2/7/2013	336	U	5.0		NS	U	5.0		NS
2/11/2013 (1,2)	257	U	5.0		NS	U	5.0		NS
2/28/2013 (1,2)	357		25.2		NS		15.8		NS
3/4/2013 (2)	361		25.0		NS		18.7		NS
3/6/2013 (2)	363		27.1		NS		17.6		NS
3/13/2013 (2)	370		32.0		NS		19.5		NS
3/14/2013 (2)	371		32.4		NS		18.7		NS
3/18/2013 (2)	375		25.6		NS		15.6		NS
3/20/2013 (2)	377		28.2		NS		18.7		NS

NS - Not Sampled

U - The compound was not detected at the indicated PQL

(1) Samples run out of hold

(2) Infuent from before FCV-104

Concentration of cis-dichloroethene (μg/L) in the influent groundwater and effluent from the FBR.

					(V-135)		(after SRT)		(V-149)
	Days		Influent		Influent		Effluent		Effluent
4/5/2012	27	U	5.0		NS	U	5.0		NS
4/10/2012	33	U	5.0		NS	U	5.0		NS
6/6/2012	90	U	5.0		NS	U	5.0		NS
6/11/2012	95	U	5.0		NS	U	5.0	U	5.0
6/13/2012	97	U	5.0		NS	U	5.0	U	5.0
6/18/2012	102	U	5.0		NS	U	5.0	U	5.0
6/20/2012	104	U	5.0		NS	U	5.0	U	5.0
6/25/2012	109	U	5.0		NS	U	5.0	U	5.0
6/27/2012	111	U	5.0		NS	U	5.0		NS
7/3/2012	117	U	5.0		NS	U	5.0		NS
7/5/2012	119	U	5.0		NS	U	5.0		NS
7/9/2012	121	U	5.0		NS	U	5.0		NS
7/11/2012	125	U	5.0		NS	U	5.0		NS
7/16/2012	130	U	5.0		NS	U	5.0		NS
7/30/2012	144	U	5.0		NS	U	5.0		NS
8/2/2012	145	U	5.0		NS	U	5.0		NS
8/6/2012	151	U	5.0		NS	U	5.0		NS
8/8/2012	153	U	5.0		NS	U	5.0		NS
8/13/2012	158	U	5.0		NS	U	5.0		NS
8/16/2012	161	U	5.0		NS	U	5.0		NS
8/20/2012	165	U	5.0		NS	U	5.0		NS
8/22/2012	167	U	5.0		NS	U	5.0		NS
8/27/2012	172	U	5.0		NS	U	5.0		NS
8/30/2012	175	U	5.0		NS	U	5.0		NS
9/5/2012	181	U	5.0		NS	U	5.0		NS
9/6/2012	182	U	5.0		NS	U	5.0		NS
9/10/2012	186	U	5.0		NS	U	5.0		NS
9/20/2012	196	U	5.0		NS	U	5.0		NS
9/24/2012	200	U	5.0		NS	U	5.0		NS
10/2/2012	208	U	5.0		NS	U	5.0		NS
10/10/2012	216	U	5.0		NS	U	5.0		NS
10/15/2012	221	U	5.0		NS	U	5.0		NS
10/22/2012	228	U	5.0		NS	U	5.0		NS
10/29/2012	235	U	5.0		NS	U	5.0		NS
11/5/2012	242	U	5.0		NS	U	5.0		NS
11/12/2012	249	U	5.0		NS	U	5.0		NS
11/19/2012	256	U	5.0		NS	U	5.0		NS
11/26/2012	263	U	5.0		NS	U	5.0		NS
12/3/2012	270	U	5.0		NS	U	5.0		NS
12/10/2012	277	U	5.0		NS	U	5.0		NS
12/17/2012	284	U	5.0		NS	U	5.0		NS
1/22/2013	320	U	5.0		NS	U	5.0		NS
1/28/2013	326	U	5.0		NS	U	5.0		NS
2/7/2013	336	U	5.0		NS	U	5.0		NS
2/11/2013 (1,2)	257	U	5.0		NS	U	5.0		NS
2/28/2013 (1,2)	357	U	5.0		NS	U	5.0		NS
3/4/2013 (2)	361	U	5.0		NS	U	5.0		NS
3/6/2013 (2)	363	U	5.0		NS	U	5.0		NS
3/13/2013 (2)	370	U	5.0		NS	U	5.0		NS
3/14/2013 (2)	371	U	5.0		NS	U	5.0		NS
3/18/2013 (2)	375	U	5.0		NS	U	5.0		NS
3/20/2013 (2)	377	U	5.0		NS	U	5.0		NS

NS - Not Sampled

U - The compound was not detected at the indicated PQL

(1) Samples run out of hold

(2) Infuent from before FCV-104

Concentration of vinyl chloride (μg/L) in the influent groundwater and effluent from the FBR.

					(V-135)		(after SRT)		(V-149)
	Days		Influent		Influent		Effluent		Effluent
4/5/2012	27	U	5.0		NS	U	5.0		NS
4/10/2012	33	U	5.0		NS	U	5.0		NS
6/6/2012	90	U	5.0		NS	U	5.0		NS
6/11/2012	95	U	5.0		NS	U	5.0	U	5.0
6/13/2012	97	U	5.0		NS	U	5.0	U	5.0
6/18/2012	102	U	5.0		NS	U	5.0	U	5.0
6/20/2012	104	U	5.0		NS	U	5.0	U	5.0
6/25/2012	109	U	5.0		NS	U	5.0	U	5.0
6/27/2012	111	U	5.0		NS	U	5.0		NS
7/3/2012	117	U	5.0		NS	U	5.0		NS
7/5/2012	119	U	5.0		NS	U	5.0		NS
7/9/2012	121	U	5.0		NS	U	5.0		NS
7/11/2012	125	U	5.0		NS	U	5.0		NS
7/16/2012	130	U	5.0		NS	U	5.0		NS
7/30/2012	144	U	5.0		NS	U	5.0		NS
8/2/2012	145	U	5.0		NS	U	5.0		NS
8/6/2012	151	U	5.0		NS	U	5.0		NS
8/8/2012	153	U	5.0		NS	U	5.0		NS
8/13/2012	158	U	5.0		NS	U	5.0		NS
8/16/2012	161	U	5.0		NS	U	5.0		NS
8/20/2012	165	U	5.0		NS	U	5.0		NS
8/22/2012	167	U	5.0		NS	U	5.0		NS
8/27/2012	172	U	5.0		NS	U	5.0		NS
8/30/2012	175	U	5.0		NS	U	5.0		NS
9/5/2012	181	U	5.0		NS	U	5.0		NS
9/6/2012	182	U	5.0		NS	U	5.0		NS
9/10/2012	186	U	5.0		NS	U	5.0		NS
9/20/2012	196	U	5.0		NS	U	5.0		NS
9/24/2012	200	U	5.0		NS	U	5.0		NS
10/2/2012	208	U	5.0		NS	U	5.0		NS
10/10/2012	216	U	5.0		NS	U	5.0		NS
10/15/2012	221	U	5.0		NS	U	5.0		NS
10/22/2012	228	U	5.0		NS	U	5.0		NS
10/29/2012	235	U	5.0		NS	U	5.0		NS
11/5/2012	242	U	5.0		NS	U	5.0		NS
11/12/2012	249	U	5.0		NS	U	5.0		NS
11/19/2012	256	U	5.0		NS	U	5.0		NS
11/26/2012	263	U	5.0		NS	U	5.0		NS
12/3/2012	270	U	5.0		NS	U	5.0		NS
12/10/2012	277	U	5.0		NS	U	5.0		NS
12/17/2012	284	U	5.0		NS	U	5.0		NS
1/22/2013	320	U	5.0		NS	U	5.0		NS
1/28/2013	326	U	5.0		NS	U	5.0		NS
2/7/2013 (1)	336	U	5.0		NS	U	5.0		NS
2/11/2013 (2)	257	U	5.0		NS	U	5.0		NS
2/28/2013 (1,2)	357	U	5.0		NS	U	5.0		NS
3/4/2013 (2)	361	U	5.0		NS	U	5.0		NS
3/6/2013 (2)	363	U	5.0		NS	U	5.0		NS
3/13/2013 (2)	370	U	5.0		NS	U	5.0		NS
3/14/2013 (2)	371	U	5.0		NS	U	5.0		NS
3/18/2013 (2)	375	U	5.0		NS	U	5.0		NS
3/20/2013 (2)	377	U	5.0		NS	U	5.0		NS

NS - Not Sampled

U - The compound was not detected at the indicated PQL

(1) Samples run out of hold

(2) Infuent from before FCV-104

Concentration of 1,2-dichlorobenzene (μg/L) in the influent groundwater and effluent from the FBR.

	Days		Influent		(V-135) Influent		(after SRT) Effluent		(V-149) Effluent
2/28/2013 (1)	357		16.7		NS	J	0.6		NS
3/4/2013 (1)	361		14.8		NS	J	0.9		NS
3/6/2013 (1)	363		15.3		NS	J	0.9		NS
3/13/2013 (1)	370		18.6		NS	J	0.6		NS
3/14/2013 (1)	371		17.4		NS	J	0.6		NS
3/18/2013 (1)	375		14.5		NS	U	5.0		NS
3/20/2013 (1)	377		15.9		NS	J	0.6		NS

NS - Not Sampled

U - The compound was not detected at the indicated PQL

J - The compound was detected at a level below the method PQL. The value reported is an estimated value.

(1) Infuent from before FCV-104

Concentration of TSS (mg/L) in the influent groundwater and effluent from the FBR.

	Days		Influent		Influent (V-135)		Effluent (after SRT)		Effluent (V-149)
4/5/2012	27		NS		NS		NS		NS
4/10/2012	33		NS		NS		NS		NS
6/6/2012	90	U	20.0		NS	U	20.0		NS
6/11/2012	95	U	10.0		NS	J	5.5		NS
6/13/2012	97	U	10.0		NS	U	10.0		NS
6/18/2012	102	U	10.0		NS	U	10.0		NS
6/20/2012	104	U	10.0		NS	U	10.0		NS
6/25/2012	109	U	10.0		NS	U	10.0		NS
6/27/2012	111	U	10.0		NS	U	10.0		NS
7/3/2012	117	U	10.0		NS	U	10.0		NS
7/5/2012	119	U	10.0		NS	U	10.0		NS
7/9/2012	121	U	10.0		NS	U	10.0		NS
7/11/2012	125	U	10.0		NS	U	10.0		NS
7/16/2012	130	U	10.0		NS	U	10.0		NS
7/31/2012	145	U	10.0		NS	U	10.0		NS
8/2/2012	145	U	10.0		NS	U	10.0		NS
8/6/2012	151	U	10.0		NS	U	10.0		NS
8/8/2012	153	U	10.0		NS	U	10.0		NS
8/13/2012	158	J	2.0		NS	J	3.0		NS
8/16/2012	161	J	4.0		NS	J	6.0		NS
8/20/2012	165	U	10.0		NS	U	10.0		NS
8/22/2012	167		40.0		NS	U	10.0		NS
8/27/2012	172	U	10.0		NS	J	5.0		NS
8/30/2012	175	U	10.0		NS	J	2.0		NS
9/5/2012	181	U	10.0		NS	J	4.0		NS
9/6/2012	182	U	10.0		NS	J	4.0		NS
9/10/2012	186	U	10.0		NS	J	4.0		NS
9/12/2012	188	J	2.0		NS	J	3.0		NS
9/20/2012	196	U	10.0		NS	J	4.0		NS
9/24/2012	200	U	10.0		NS	J	2.0		NS
9/26/2012	202	U	10.0		NS	J	3.0		NS
10/2/2012	208	U	10.0		NS	J	4.0		NS
10/4/2012	210	U	10.0		NS	J	5.0		NS
10/10/2012	216	U	10.0		NS	J	4.0		NS
10/11/2012	217	U	10.0		NS	J	3.0		NS
10/15/2012	221	U	10.0		NS	J	4.0		NS
10/17/2012	223	U	10.0		NS	J	4.0		NS
10/22/2012	228	U	10.0		NS	J	4.0		NS
10/24/2012	230	U	10.0		NS	J	4.0		NS
10/29/2012	235	U	10.0		NS	U	10.0		NS
11/5/2012	242	U	10.0		NS	J	7.0		NS
11/7/2012	244	U	10.0		NS	J	9.0		NS
11/12/2012	249	U	10.0		NS	U	10.0		NS
11/14/2012	251	U	10.0		NS	U	10.0		NS
11/19/2012	256	U	10.0		NS	U	10.0		NS
11/26/2012	263	U	10.0		NS	U	10.0		NS
11/28/2012	265	U	10.0		NS	U	10.0		NS
12/3/2012	270	U	10.0		NS	U	10.0		NS
12/5/2012	272	U	10.0		NS	U	10.0		NS
12/10/2012	277	U	10.0		NS	U	10.0		NS
12/12/2012	279	U	10.0		NS	J	3.0		NS
12/17/2012	284	U	10.0		NS	U	10.0		NS
12/19/2012	286	U	10.0		NS	U	10.0		NS
1/22/2013	320	J	2.0		NS	J	3.0		NS
1/28/2013	326	J	2.0		NS	J	3.0		NS
2/7/2013	336	U	10.0		NS	J	2.0		NS
2/11/2013 (1,2)	257	U	2.0		NS	J	2.0		NS
2/28/2013	357		54.0		NS	J	3.0		NS
3/4/2013	361		23.0		NS	J	3.0		NS
3/13/2013	370	J	4.0		NS	J	4.0		NS
3/20/2013	377	U	2.0		NS	J	6.0		NS

NS - Not Sampled

U - The compound was not detected at the indicated PQL

J - The compound was detected at a level below the method PQL. The value reported is an estimated value.

(1) Samples run out of hold

(2) Infuent from before FCV-104